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Growth and yield response of red pine plantations to thinning

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Growth and yield response of red pine plantations to thinning

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Introduction

The establishment of red pine (*Pinus resinosa* Ait.) plantations throughout southern and central Ontario has been underway for over 70 years. Many of the early plantations are approaching final harvest. Many other young and mid-age stands are in an 'over-crowded' condition and require a thinning treatment to ensure timely product development.

Current Ontario red pine plantation yield tables (Beckwith *et al.* 1983) and (Berry 1984) have been used by resource managers over the past 15 years with limited success. Both publications were based on "state of the art" approaches but were developed with a) limited data sets and b) incomplete ranges of ages (most stands studied had not reached rotation age) and site conditions. Neither set of tables easily permit a manager to compare the expected growth or yield following single or multiple thinning treatments (at different ages) versus no density management at all. With this lack of a "What if I thin this much at this time?" capability, these sources were used sparingly.

This report uses many of the same plots as the earlier yield tables but includes an additional 15 years of growth data to examine the response of red pine to thinning. The predicted response is provided as yield tables and graphically.

Research and demonstration plots across Ontario established in the 1930s and 1940s are now yielding substantial data on plantation red pine stand development resulting from unthinned, single or multiple row thinning activities. A new analysis of the current data on red pine response to thinning was felt timely.

Objectives

The objectives of the project were to:

- refine and update previously published yield table estimates (Beckwith *et al.* 1983, Berry 1984) based on longer time-lines of plot development;
- develop a model form(s) that would allow projection of density/basal area/quadratic mean diameter development following a thinning of any amount at any time; and
- explore the expected response of red pine stands to thinning (basal area (G), gross total volume (GTV), gross merchantable volume (GMV), total production (thinned + standing volume), periodic annual increment (PAI = mean five year GMV increment).

Model Development

Data Sources and Location

Two red pine plantation datasets were used for model development and calibration. The Beckwith dataset and the Petawawa Research Forest (PRF) dataset. Both datasets consist of long-term remeasured permanent sample plots that are located throughout the Southcentral region of Ontario (Figure 1). The Beckwith plots comprise various operational experiments, usually incorporating a number of thinning treatments and often a control plot. The thinnings generally consisted of an initial row thinning (usually the removal of every third row) followed by some sort of selection thinning based on a target stand density index (SDI). Some of the plantations were established on abandoned farmland and others on blowsands. In a few instances the initial measurements were only diameter at breast height (d) tallies (trees were not tagged). Summaries from these measurements are included.

Examination of the dataset indicated that three control plots (Hendm15, Neorr6 and Vivian13) displayed

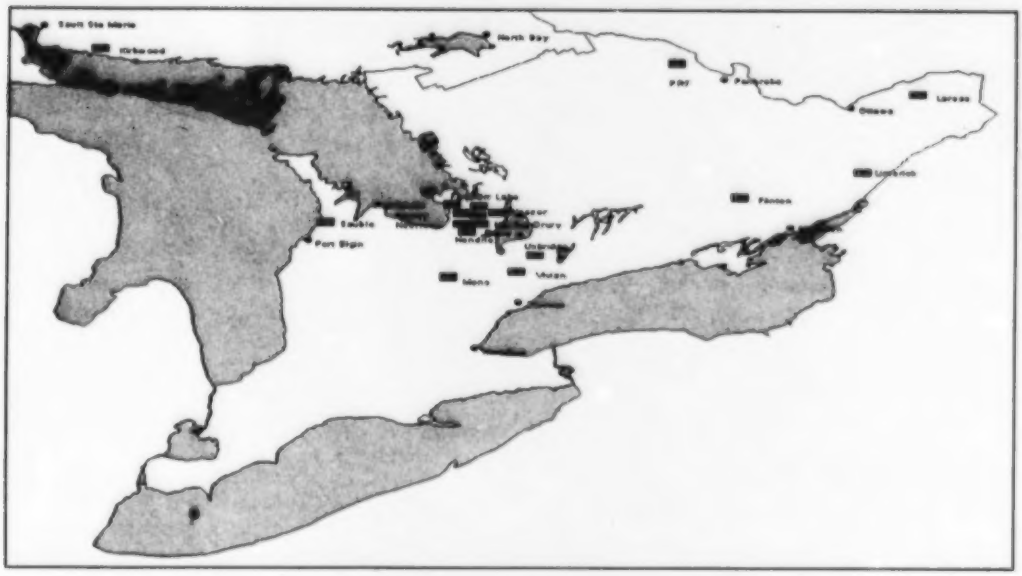


Figure 1. Permanent Sample Plot locations.

significantly higher mortality rates when compared to other sampled stands of similar ages and densities. These plots were removed from the initial modelling efforts. A discussion of the unexpected high rates of mortality is provided later in the report.

The PRF dataset comes from a large spacing/thinning experiment established in 1953 at the Petawawa Research Forest (PRF). Blocks were planted at initial densities ranging from 1.2m to 4.3m spacing and one area juvenile spaced to 6.1m In 1982 and 1992, portions of the blocks were thinned to comparable residual basal areas.

Table 1 provides an attribute description of the two datasets used.

Methods

Mensurational summaries were completed for each plot measurement. The list includes density (N, stems/ha), basal area (G, m^2/ha), quadratic mean diameter (d_g, cm), height estimates (h, m), site index (S [m] at breast height age 50 years), and volume (gross total [GTV] and gross merchantable [GMV], m^3/ha).

Height-dbh curves

At each plot remeasurement, heights were measured on a sample of trees taken across the range of available diameter classes. For trees without height measurements, heights were estimated using height–dbh curves calibrated for each plot and measurement, interpolated from neighboring plots, or from the remaining measurements.

The following Chapman-Richards model form (Zeide 1993) was used:

$$h = 1.3 + \beta_0 \cdot (1 - e^{-\beta_1 d})^{\beta_2} \qquad \text{where} \quad \beta_0, \beta_1, \beta_2 > 0$$

where h = height (m)

d = diameter at breast height (cm)

$\beta_0, \beta_1, \beta_2$ = coefficients to be estimated

Table 1. A description of individual Beckwith and Petawawa Research Forest (PRF) red pine data sets. Note that the initial conditions refer to the first measurement at which the trees were tagged. In some cases historical data are available in the form of plot summaries for measurements taken before the trees were tagged.

Attribute	Mean (range)		
	Beckwith		PRF
	All plots	Control plots	Control plots
Number of plots	119	19	15
Plot size (ha)	0.08 (0.04-0.20)	0.08 (0.04 - 0.20)	0.13 (0.10 - 0.20)
Measurement interval (years)	4.51	3.49	5
Initial age (years from planting)	29 (11-52)	26 (11 - 44)	10
Approximate initial spacing (m)[1]	2.2 (N/A[1] - 1.8)	2.1 (2.7 - 1.8)	2.0 (4.5 - 1.3)
Initial density (stems/ha)	2011 (N/A - 3125)	2363 (1333 - 3125)	2548 (504 - 5988)
Age at last measurement	57 (31 - 74)	51 (36 - 74)	45
Initial d_g (cm)	15.1 (6.2 - 29.8)	14.1 (7.1 - 18.2)	5.1 (4.3 - 5.9)
Final d_g (cm)	24.6 (12.8 - 38.6)	20.8 (14.2 - 24.7)	22.2 (15.5 - 25.3)
Initial top height (m)	13.3 (4.3 - 21.7)	13.0 (4.8 - 20.4)	4.5 (4.1 - 4.9)
Final top height (m)	22.1 (11.7 - 30.6)	21.7 (11.7 - 27.4)	22.7 (20.9 - 24.2)
Site index (m @ bh[2] age 50)	22.2 (14.5 - 27)	23.1 (17 - 26)	26
Age of first thinning	26.8 (11 - 44)	N/A	N/A
Depletion (%)	16.6 (1 - 57)	N/A	N/A

[1]Initial density of some plots is unknown

[2]breast height (bh) is 1.3m (metric or 4.5ft (imperial)

Volume

Inside bark volumes were estimated using the red pine variant of a 4 parameter taper model (Woods and Zakrzewski 2000). If an appropriate species volume equation did not exist, a suitable species match was used. Merchantable volumes were calculated as the inside bark volume between a 30cm high stump to a 10cm top diameter. Product volumes were calculated according to standards in Table 2. Trees must also meet knot and stem form criteria in order to qualify as poles but the data did not permit evaluation of this. Although there is a market for longer poles, the pole volume reported here was calculated using the minimum dimensions.

Table 2. Minimum dimensions for various red pine products.

Product	Length (m)	Top diameter (cm)	Additional requirements
Pole	12.1	12.1	23.6cm diameter 1.8m from base
Sawlog (16 foot)	5	20	
Sawlog (8 foot)	2.5	20	
Bolt (8 foot)	2.5	10	
Pulp	N/A	10	

Estimating d_g and density change for the control plots

Basal area, initial plantation density, and thinning intensity have a large impact on stand quadratic mean diameter and the rate of stand mortality. For these reasons, all were used as predictor variables. Martin and Ek (1984) found that plot basal area was a good measure of competitive stress in red pine plantations, possibly as a result of the generally uniform spacing. In an attempt to develop a model sensitive to these relationships, the focus of the modelling efforts centered on d_g growth and the rate of density change.

The annual d_g growth between two measurements, Dd_g, was calculated as the difference between the first post-thinning d_g and the subsequent pre-thinning d_g divided by the measurement interval. Changes in density, DN, were calculated in a similar manner. The 34 control (i.e., no thinning) plots were selected for the model fitting. Various model forms were fit to the data. The best predictions (best overall agreement with the data from the control plots) were the following equations (all attributes are stand attributes):

$$\Delta d_g = \alpha \cdot d_g^{\beta} \cdot e^{\gamma + \delta \cdot G + \varphi \cdot age} \qquad \text{where,}$$

$$\hat{\alpha} = 3.000$$
$$\hat{\beta} = 0.33136405$$
$$\hat{\gamma} = -1.184620198$$
$$\hat{\delta} = -0.048997162$$
$$\hat{\varphi} = -0.003352253$$
$$MSE = 0.00758, df = 138$$

$$\Delta N = -\gamma \cdot N^3 \cdot (1 - e^{(\alpha + \beta G) age}) \qquad \text{where,}$$

$$\hat{\alpha} = 0.0000082027$$
$$\hat{\beta} = -0.0000256483$$
$$\hat{\gamma} = 0.0000000217$$
$$MSE = 230, df = 145$$

Note that both equations require initial stand values for age, d_g, and N (density). The diameter growth equation is similar to the differential form of the monomolecular growth model and the change in density equation is similar to the Chapman-Richards model (Zeide 1993).

The change in density model given above should be considered as providing an optimistic prediction for unthinned plantations at older ages. Although some control plots remain healthy despite exhibiting low growth rates others appeared to be at higher risk of significant mortality.

Data independence

Some of the plots were part of the same experiment, i.e., not all of the plots were independent. As well, remeasurements on the same plot are correlated. This violates the regression assumption of independent errors. Although this violation affects the variance estimates and hypothesis tests (West 1995), it does not lead to biased parameter estimates or predictions. Therefore, the violation of independence was ignored and the models were mainly evaluated by visually inspecting the predictions versus actual data. The predictions based on the age, d_g, and density at the first measurement showed close agreement with the actual data (Figure 2).

Estimating top height

Top height was used in the estimation of SI for each plot. The SI estimates were based on the red pine plantation site index equations in Appendix A of Smith and Woods (1997) based on the earlier work of Beckwith *et al.* (1983). For this report, top height (h_T) of a stand is defined as the average height of the 100 largest diameter trees per hectare. The plot sizes were less than 1ha so the numeric equivalent of 100 trees/ha was used (e.g., 8 trees on a 0.08ha plot). Plot top height development is projected through time along a site index curve (Figure 3) and is generally accepted as independent of common ranges of density. Analysis of the red pine data found no evidence of a significant effect of density on top height for the plantations used here.

In addition, based on the similarity of the observed top height development trends from the permanent sample plots and the published SI curves, the SI curves were used to estimate site productivity and stand height through time in the modelling efforts.

Estimating volume

Stand volume (m^3/ha) was estimated using the following equations:

$$GTV = 15.3619 + 0.00003369 \times d_g^2 \times h_T \times \text{density} \qquad r^2 = 0.98$$
$$GMV = -24.0126 + 0.00003187 \times d_g^2 \times h_T \times \text{density} \qquad r^2 = 0.97$$

The model form assumes a relatively constant tree form. By using an average tree form, the effects of thinning on volume production will be somewhat lessened. Figure 2 provides the average observed values and the predicted (along with the 95% mean prediction intervals) of both volume equations.

Predicting d_g growth and density change following thinning

Models from the previous section were applied to the plots that had been thinned. Recall that the predictions were based on the age, d_g, and N at the first measurement. Reducing the density to the actual post thinning density simulated thinning. In general, the predictions were close to the actual growth. The predictions would be closer if the d_g was adjusted as well as the density since leaving the d_g unadjusted assumes a regular (average or row) thinning. Thinning from below or above affects the residual d_g either positively or negatively. Prediction errors for all thinned plots are summarized in Appendix A. Specific examples are provided in the next section.

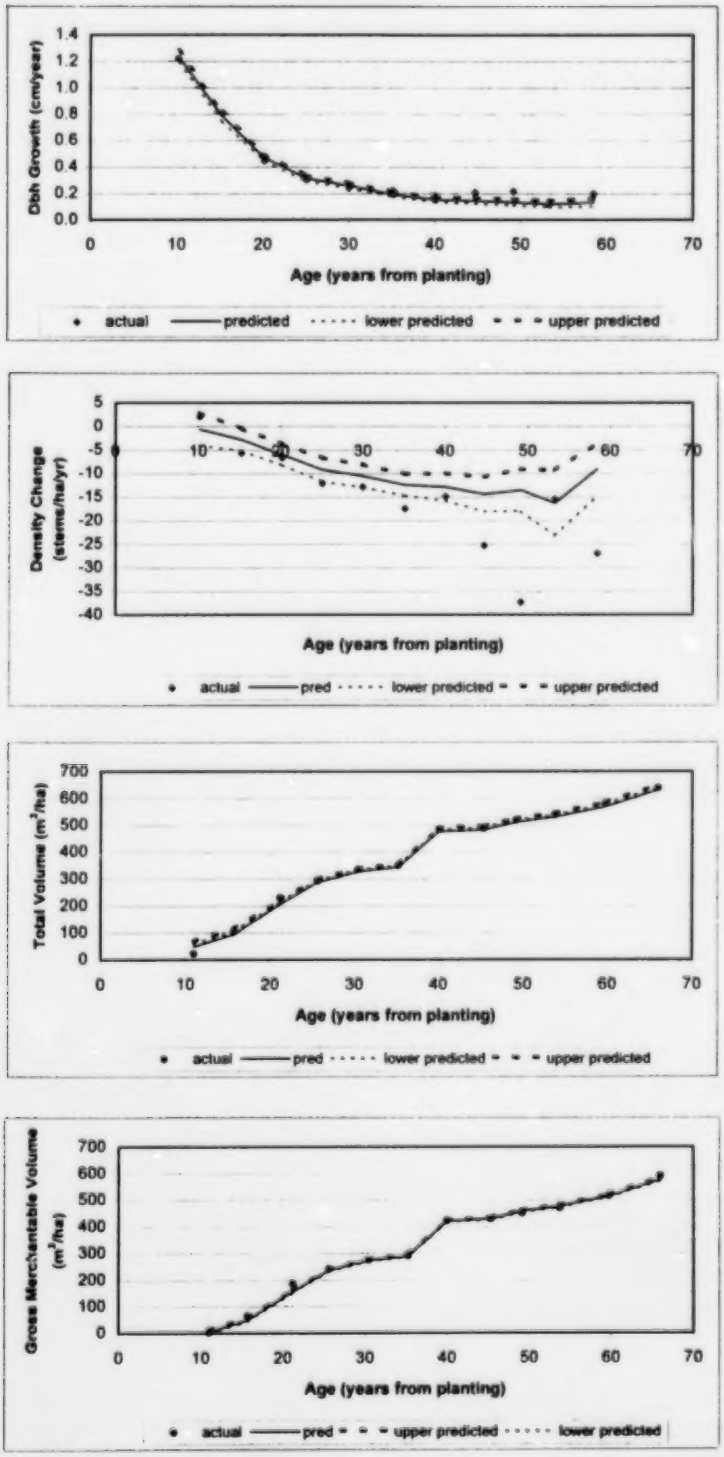


Figure 2. The average observed values for the unthinned plots are given by 5 year age class along with the predictions and the upper and lower 95% mean prediction intervals.

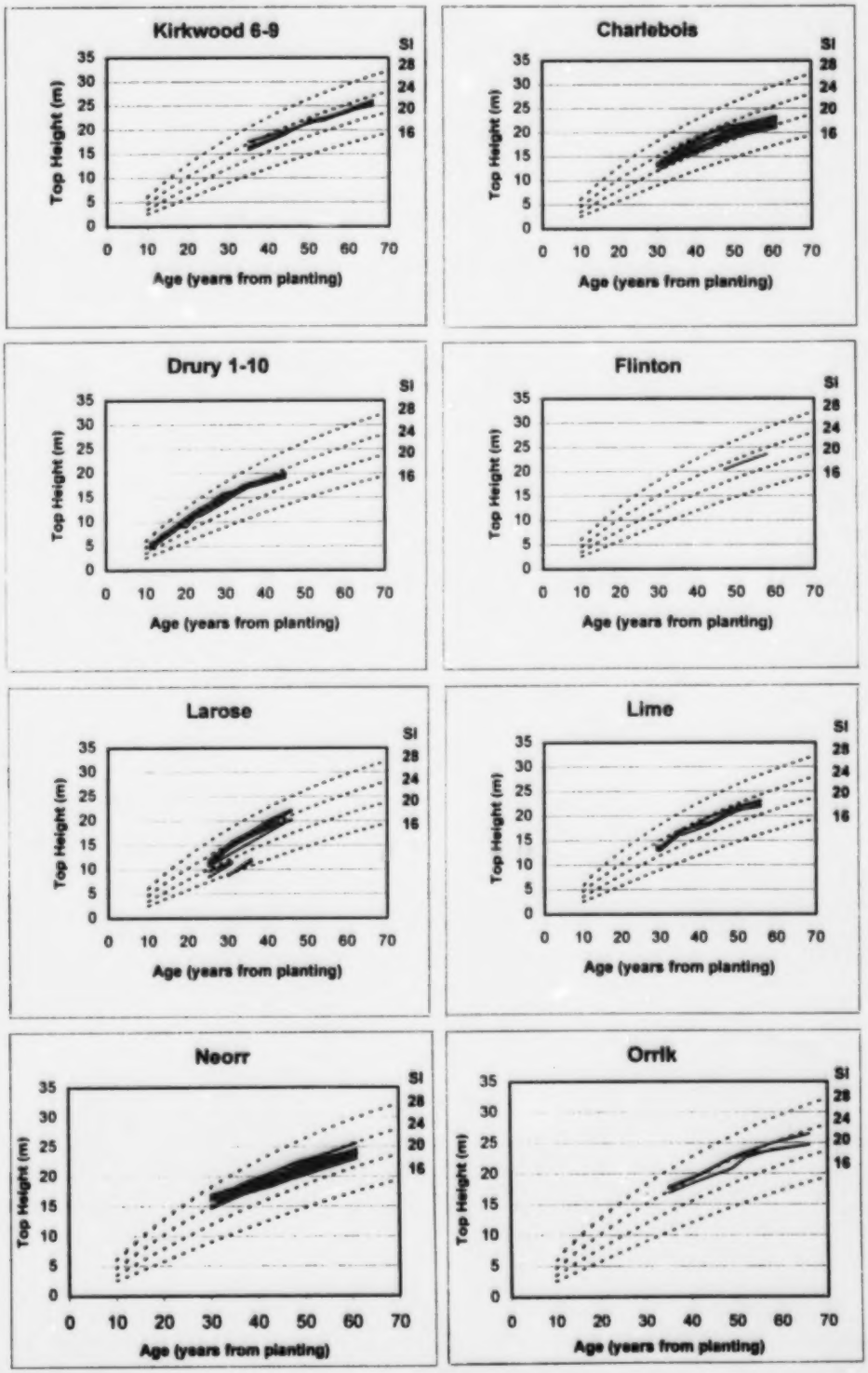


Figure 3. Top height development of selected plots compared to the site index curves of Beckwith *et al.* (1983) (modified by Smith and Woods 1997).

Model Discussion

The derived models generally represent the data well (see Figures 4–8). Predictions in Figures 4–8 are based on the d_g and stem density from the initial measurement. Thinnings are simulated by replacing the predicted stem density with the actual density following the thinning (e.g., a 2000 stems/ha stand with a 25% depletion [every 4th row removal] would leave a residual stand of (2000 × .75) = 1500 stems/ha). Therefore, the actual and predicted stem densities are close for the thinned stands. Again, reducing the stem density and leaving the d_g unaltered implies a regular (average or row) thinning. In order to simulate a thinning from above (i.e., removal of largest diameters) or below (i.e., removal of smallest diameters), the model requires both the post–thinning stem density and d_g (or stem density and basal area).

The predictions are unbiased overall but may be biased at the individual plot (stand) level. That is, some plots may grow slower or faster than an average plot at the same age, d_g, and stem density. These biases at the plot level tend to accumulate as the prediction interval increases. Therefore, the prediction interval gets wider over time, particularly when extrapolating beyond the range of data.

Figure 4 provides an example of a relatively good fit of the model. The model is initialized with age 11 data and by age 44, the control plot (plot 15) d_g is slightly overpredicted and the density underpredicted while the basal area is almost unbiased. Conversely, the model predictions for the thinned stands underpredict d_g and overpredict density and the basal area predictions are quite good. In general, the predictions of d_g and density provide negative feedback for one another. If d_g is underpredicted but the density is close, the predicted basal area will be lower than actual and the model will generally predict higher d_g growth leading to more basal area.

Using models calibrated on control plots to predict growth on thinned plots assumes that thinned stands will develop the same as unthinned stands with the same combination of age, d_g, and stems. That is, there is no appreciable effect of the pre-thinning competition on the post-thinned stand, or that all the effect is captured in the combination of age, d_g, and stems. This assumption may be reasonable when the thinning levels are relatively light. However, a heavy thinning in a crowded plantation may leave tall, thin trees with smaller crowns compared to an equivalent unthinned stand. The thinned stand may be more susceptible to wind, snow, and ice damage and have higher subsequent mortality than an unthinned stand. For example, a plot located near Sauble Beach, Ontario (Sauble10) shows considerable mortality following a second thinning, which removed nearly 50% of the basal area. The model does not predict this sort of catastrophic mortality which is not the result of intra-specific competition. As well, the model does not incorporate any thinning delay where trees expand crowns and roots before exhibiting an increase in d_g growth. This is more important with heavier later initial thinnings.

Including initial density in the stem change model implies that stands have some "memory". Stands that reach the same d_g and density from different initial densities will develop differently. Stands with higher initial densities will have greater stem mortality over time compared to stands initialized at lower densities.

Model Validation

The model was calibrated on the control plots only and appears to predict the thinned plots quite well, providing some validation for the model (Appendix A). In order to provide a more independent validation, additional permanent sample plot data were obtained from PRF. These plots were located in the same geographical area as some of the development data sets, however they were part of other experimental compartments and can be treated as independent.

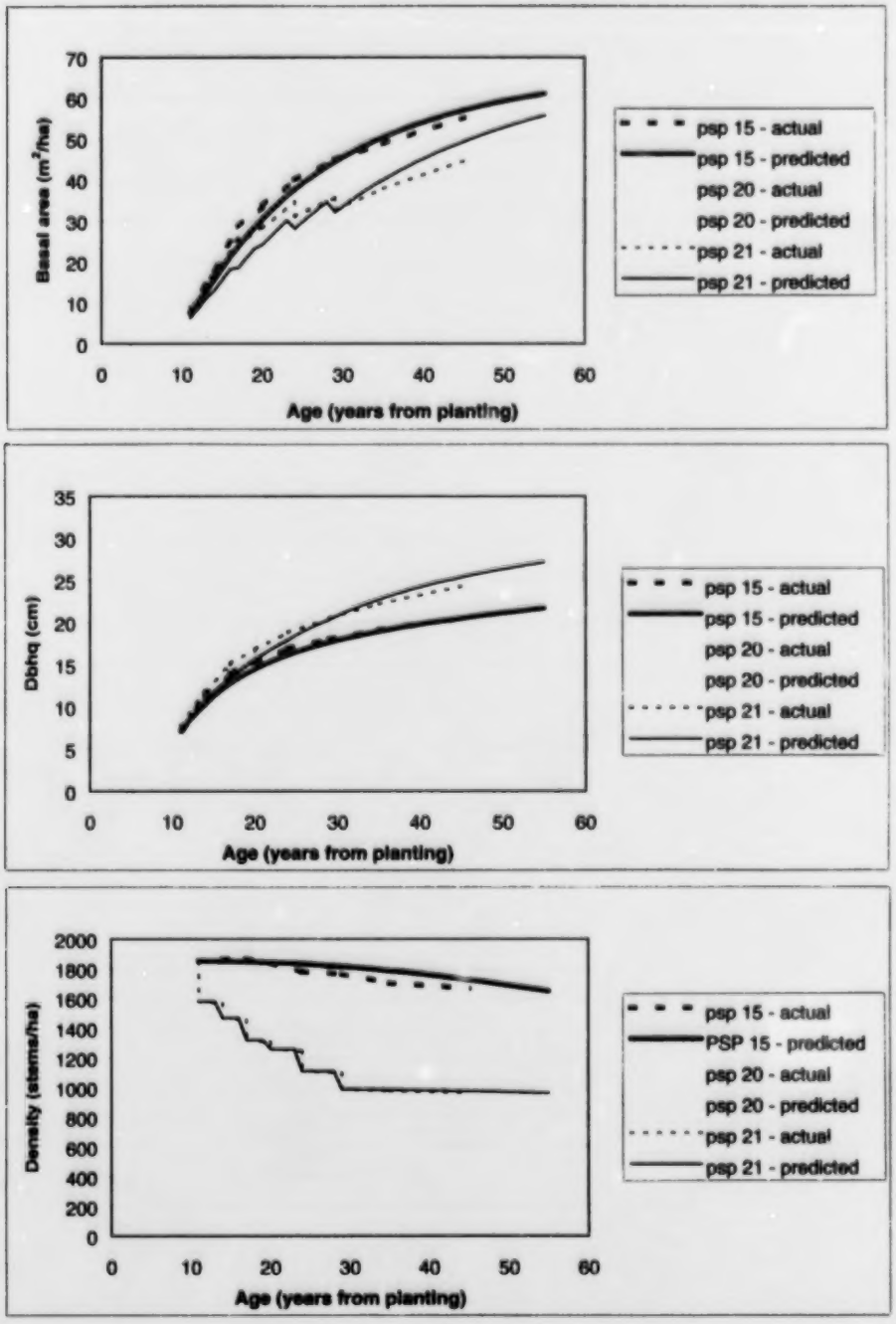


Figure 4. Predictions for 3 sample plots in Drury are plotted along with the actual data. Site indices (m @ bh age 50) are 22.3, 23, and 22 for plots 15, 20, and 21 respectively.

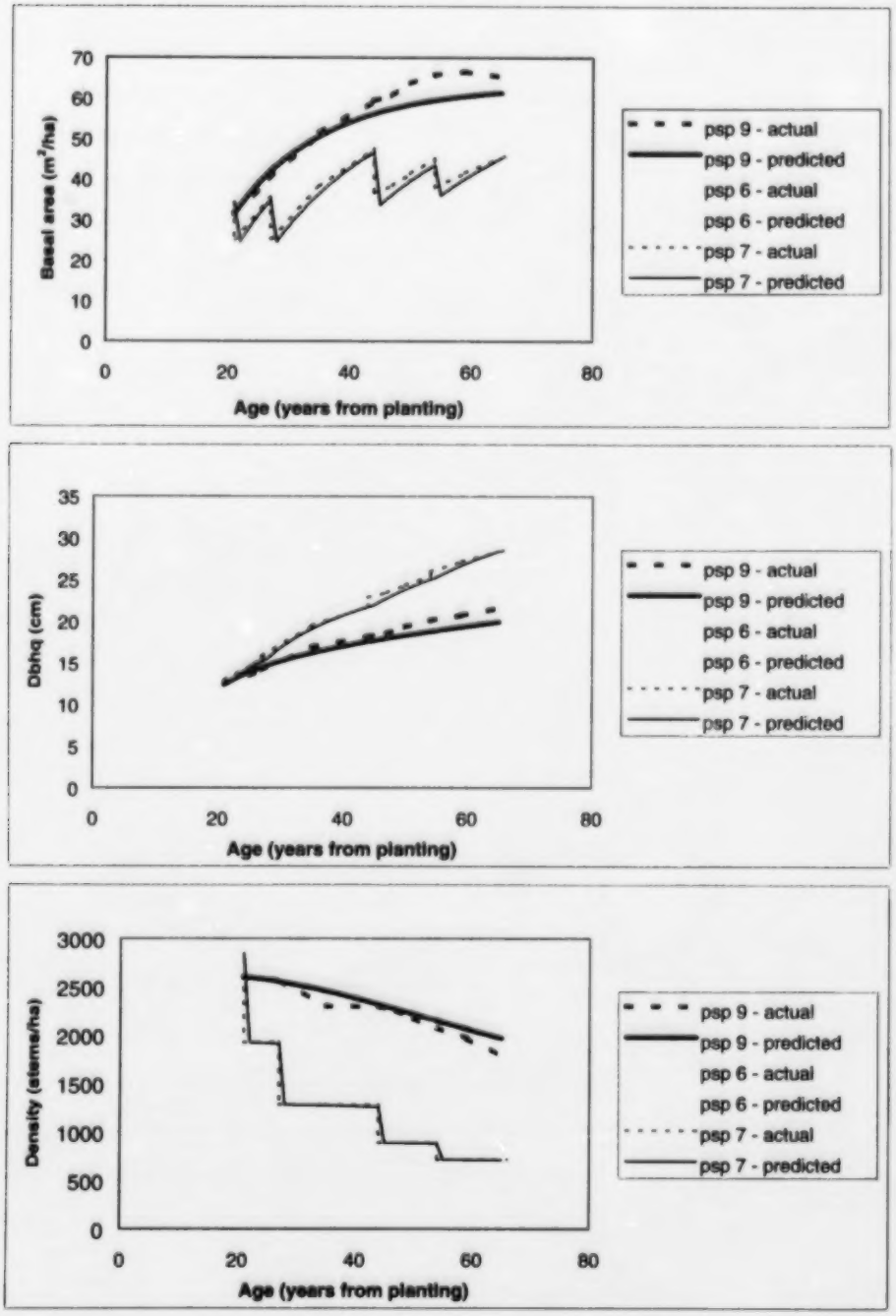


Figure 5. Predictions for 3 sample plots in Kirkwood are plotted along with the actual data. Site indices (m @ bh age 50) are 23, 23, and 22 for plots 9,6, and 7 respectively.

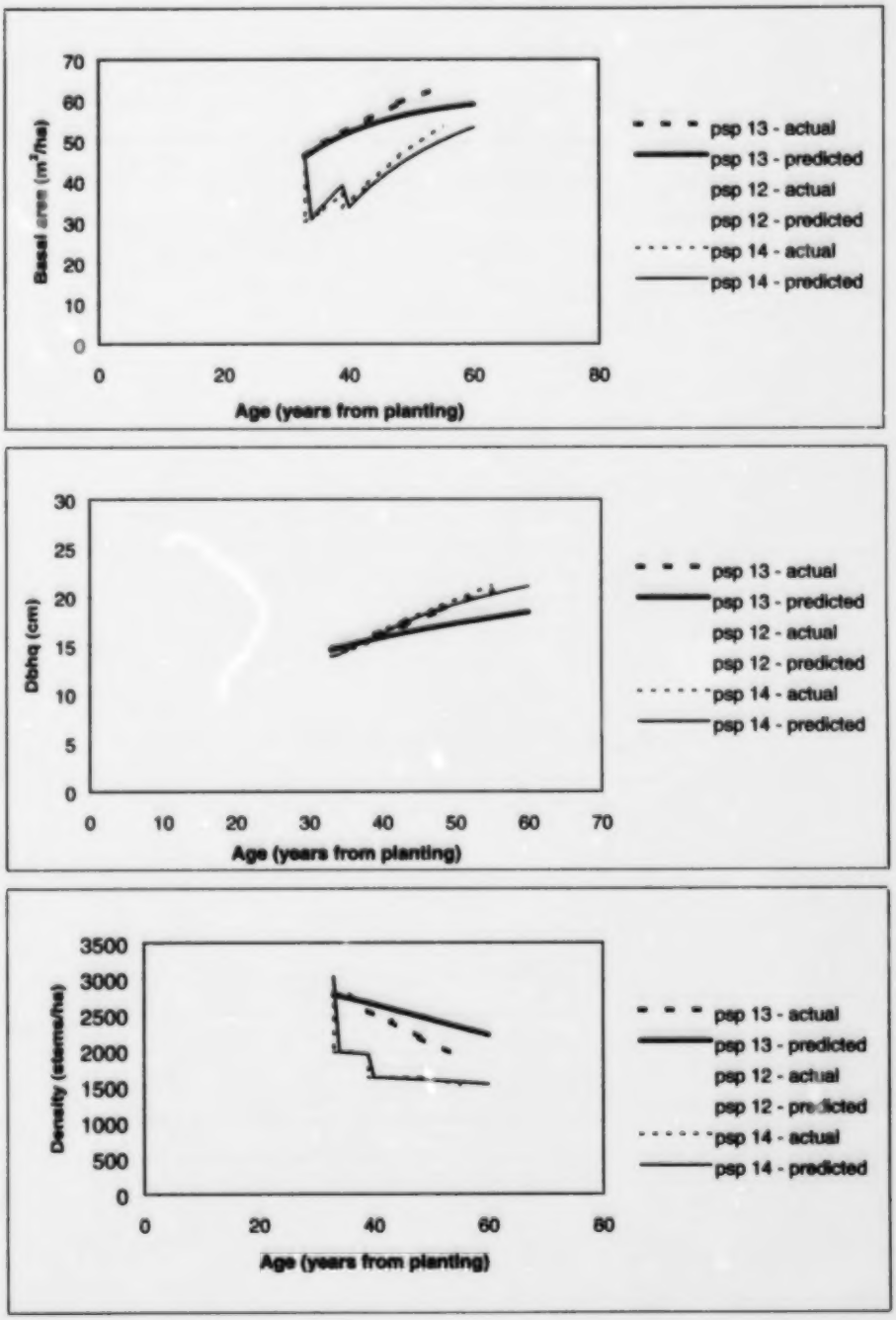


Figure 6. Predictions for 3 sample plots in Kirkwood are plotted along with the actual data. Site index (m @ bh age 50) is 17m for all plots.

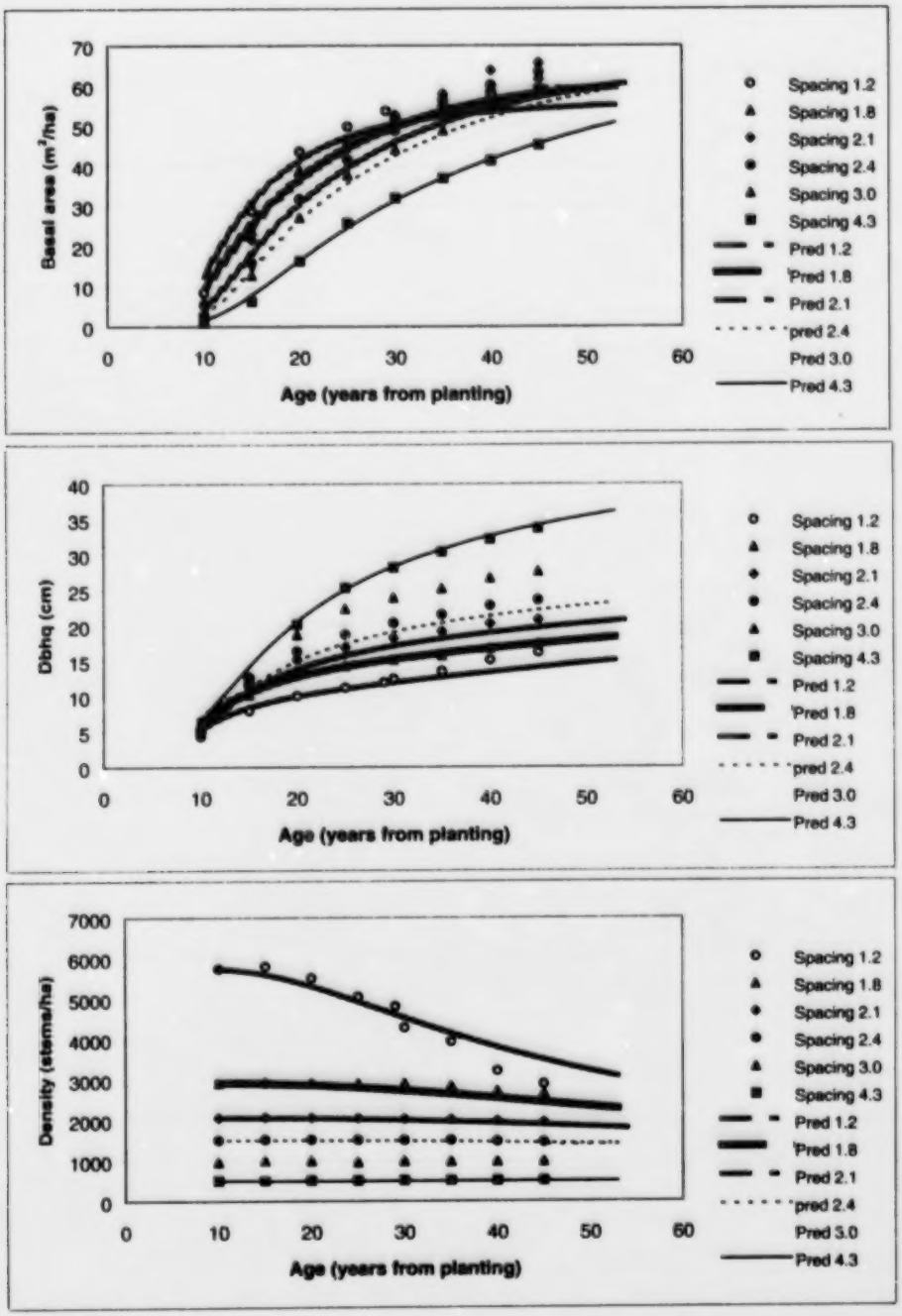


Figure 7. Predictions for some of the PRF sample plots are plotted along with the actual data. Site index (m @ bh age 50) is 26m for all plots. Note that two plots are averaged at each of the spacings.

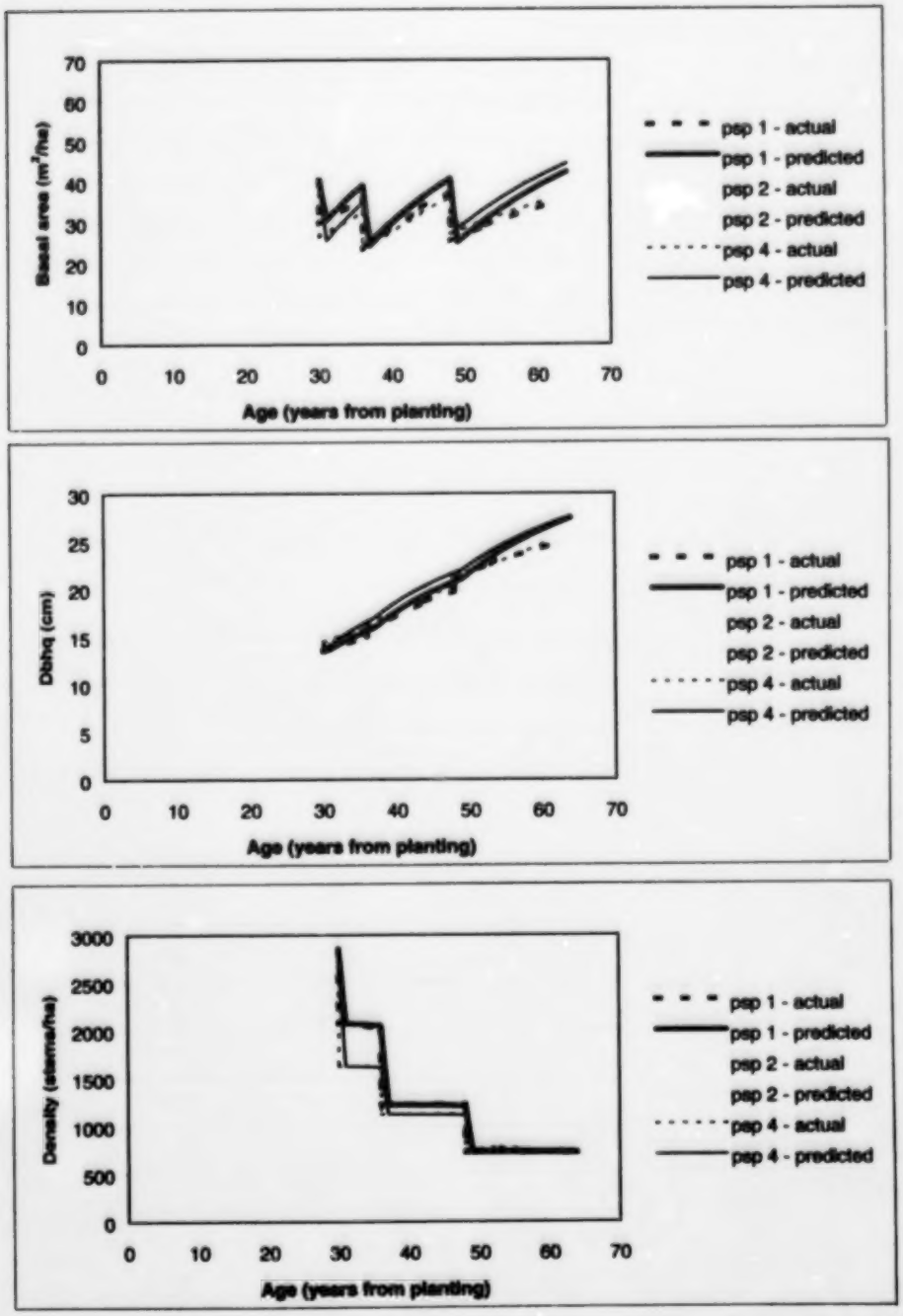


Figure 8. Predictions for 3 sample plots in Charlebois are plotted along with the actual data. Site indices (m ● bh age 50) for plots 1, 2, and 3 are 21m, 20m and 21.5m respectively.

The test data was part of a spacing trial planted in 1927. Initial spacings of the plots varied from 1.7 × 1.7m, 2.1 × 2.1m and 3.0 × 3.0m (Plot 194 was originally planted at 2.1 × 2.1m spacing and was thinned 13 years after planting to 3.0 × 3.0 m). PSPs were established in the plantations in 1940 and remeasured at varied intervals until today.

Figures 9 and 10 present the results of the test data in terms of absolute differences (numbers and percent) between predicted and observed values for d_g and density. Individual plot data and averaged values are presented. It should be noted that the x-axis of the graphs represents length of prediction period and not age since planting.

The model performs adequately over a 30-year projection period for both the predictions of d_g and density. As the prediction period exceeds 30 years the estimates of density become less reliable (>5% average error). However, the prediction of d_g development does not exceed 5% average error until approximately 40 years into the projection period. As in the case with most mathematical simulations of stand development, longer projection periods are less reliable than shorter ones.

Impact of *Armillaria* spp. in red pine plantation yield

As discussed earlier, three Beckwith control plots were removed from the above reported model calibration due to their excessive rates of mortality. Removal of these control plots affected mainly the stem change model. Since mortality is very low in the thinned plots, the removal of the three plots mainly affects the density predictions for unthinned plantations.

Site visits of the removed plots resulted in the discovery of *Armillaria* epicenters contributing to the excessive rate of observed mortality. *Armillaria* appears able to cause mortality to stems that are, and have been, in an overcrowded condition for an extended period of time. This is the case for the permanent sample plots discussed here.

Whitney (1988) found red pine to be the least susceptible softwood to *Armillaria*-caused mortality. He found that in young (6–21 years) red pine plantations, mortality owing to *Armillaria* ranged from 0.2% to 13.7%. His sampling also determined a range of 0.3% to 15.4% mortality in older (43–53 years) aged red pine plantations. Some of the older Beckwith plantations show considerably higher rates of mortality (e.g., 76% of the stems in Vivian Plot 13 died between the ages of 39 and 74 years).

It was interesting to note that in cases where control plots were situated in close proximity to regularly thinned plots the thinned plots displayed no evidence of the *Armillaria* reducing their growth rates or causing any pathologic mortality. It is surmised that regular thinning of the stand allowed the plots to cope with the additional stress of the *Armillaria*. Whitney (1988) reported sampling older stands with densities much lower than initial planting densities encountered in this study. Therefore, we believe that in many cases the 43–53 year old stands that were reported on had been previously thinned. Prior thinning action would have moved some of those stands from an overcrowded condition to a state that they could more readily withstand the effects of the *Armillaria*. In addition, thinning activities most likely would have extracted the smaller, poorer growing trees; thereby removing the most susceptible candidates for *Armillaria* mortality. This hypothesis would explain why the reported percentages are somewhat less than witnessed in this study.

The negative impact of *Armillaria* on stand development and yield should be a concern to resource managers. A yield table model that incorporates the impacted plots is provided in an Appendix. Managers who feel they are predicting growth and yield of plantations in an area exhibiting *Armillaria* or feel they are prone to the disease are recommended to use the model provided in Appendix B.

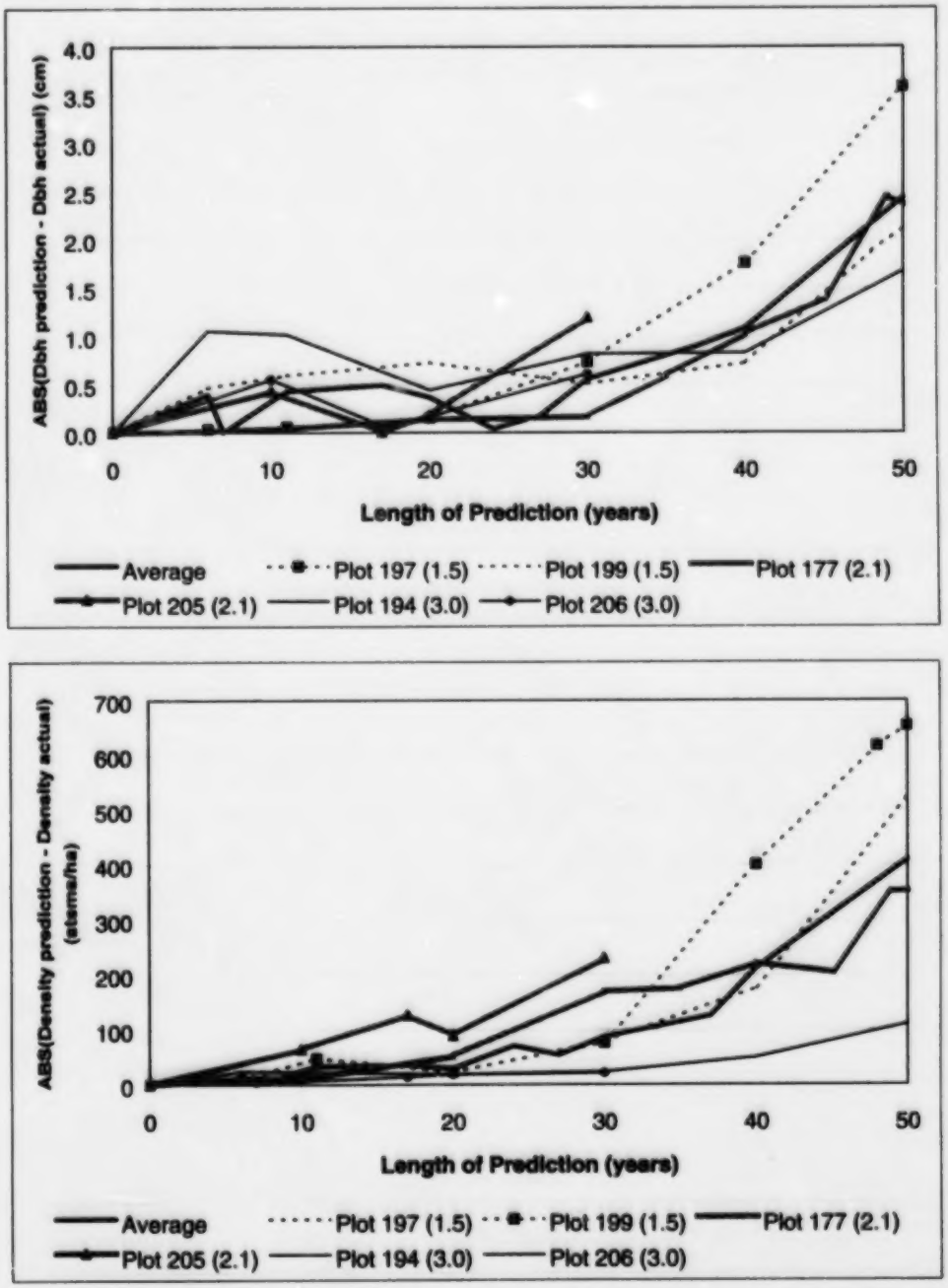
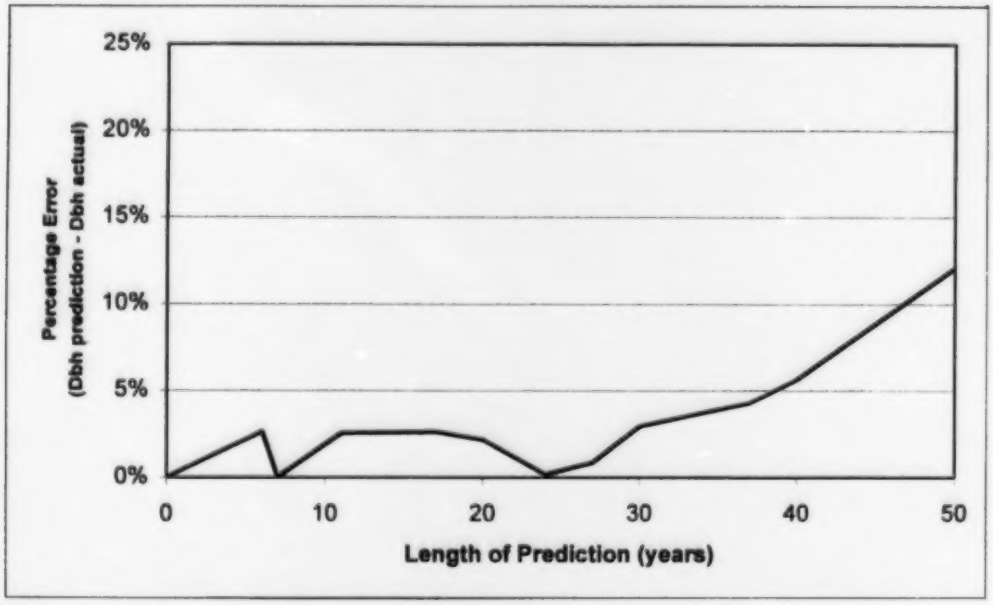


Figure 9. Absolute value of the prediction errors are given for PSPs 197, 199, 177, 205, 194 and 206 planted at initial spacings of 1.5 x 1.5m, 2.1 x 2.1m, 3.0 x 3.0m. PSP 194 was spaced to 3.0 x 3.0m 13 years after planting. The heavy line is the average error of all the plots.



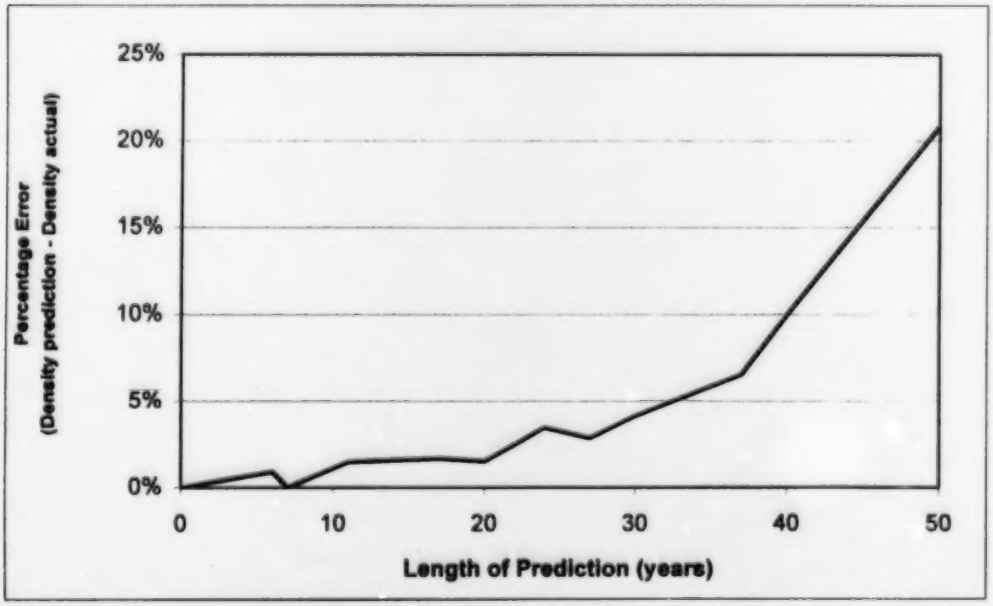


Figure 10. Average absolute relative prediction error ((predicted - actual)/predicted x 100) is given for the same data as in Figure 9.

Response to spacing and thinning

Model predictions of response to thinning need to be evaluated in terms of how well they describe the response to thinning observed in the dataset. The response to thinning can vary with the initial density, site index, age of thinning, and thinning intensity. As well, the timing and extent of thinning will vary depending on the objectives of management (maximize pole production vs. maintaining a relatively closed canopy for habitat).

Initial density

Figure 11 and Table 3 portray the predicted response to regular (row) thinning for three initial spacings, 1.5m, 2m, and 3m. The basal area of the narrowest spacing peaks earliest but starts to decline due to significant mortality so that at age 80, there is less than a $10m^2$/ha difference between the narrowest and widest spacings for the unthinned stands. However, the narrower spacings also have a greater risk of severe mortality. There are slight gains in total production from thinning in all three spacings but the biggest benefit is the increase in d_g—each thinning produced an increase of about 5cm in the d_g. Two thinnings are required at the narrower spacings to produce utility poles by age 80.

Lundgren (1981) found the mean annual increment decreased rapidly as the initial density fell below 500 stems/ha and leveled off as initial densities approach 3000–4000 stems/ha.

Site index

Site index does not appear to have consistent effects on mortality. However, site index does have a large effect on total production (Figure 12 and Table 4). Lundgren (1981) found that a similar relationship between yield and initial spacing and thinning held across a wide range of site indices. Our results agree with his in that better sites appear able to support higher basal areas throughout a rotation because of higher initial d_g.

Timing of initial thinning

The d_g of red pine plantations appears to respond positively to an initial thinning over a wide range of ages. The latest timing of initial thinning in the data set was Stoney4 (age 44). However, some plots with similar high basal areas and densities had severe mortality. Therefore, although delaying the initial thinning may increase the revenue associated with the thinning, the delay also increases the risk of significant volume loss to mortality on a per hectare basis. The predictions presented in Figure 13 and Table 5 are optimistic since they do not include the increased risk of mortality associated with high densities and basal areas. In addition, the earlier the thinning, the larger the individual tree volume at rotation (see also Oliver and Larson, 1996, p.351).

The longer a plantation remains in an overcrowded condition, the greater the degree of size and crown stratification and the greater the difference between dominant trees and suppressed trees. The models used here describe the development of average trees but as the variability of the individuals increase, the worse the predictions will be as some of the smaller individuals will not have the crown mass to respond to the thinning.

Operationally, thinning becomes more difficult as tree height increases and there may be considerable damage to the residual stand.

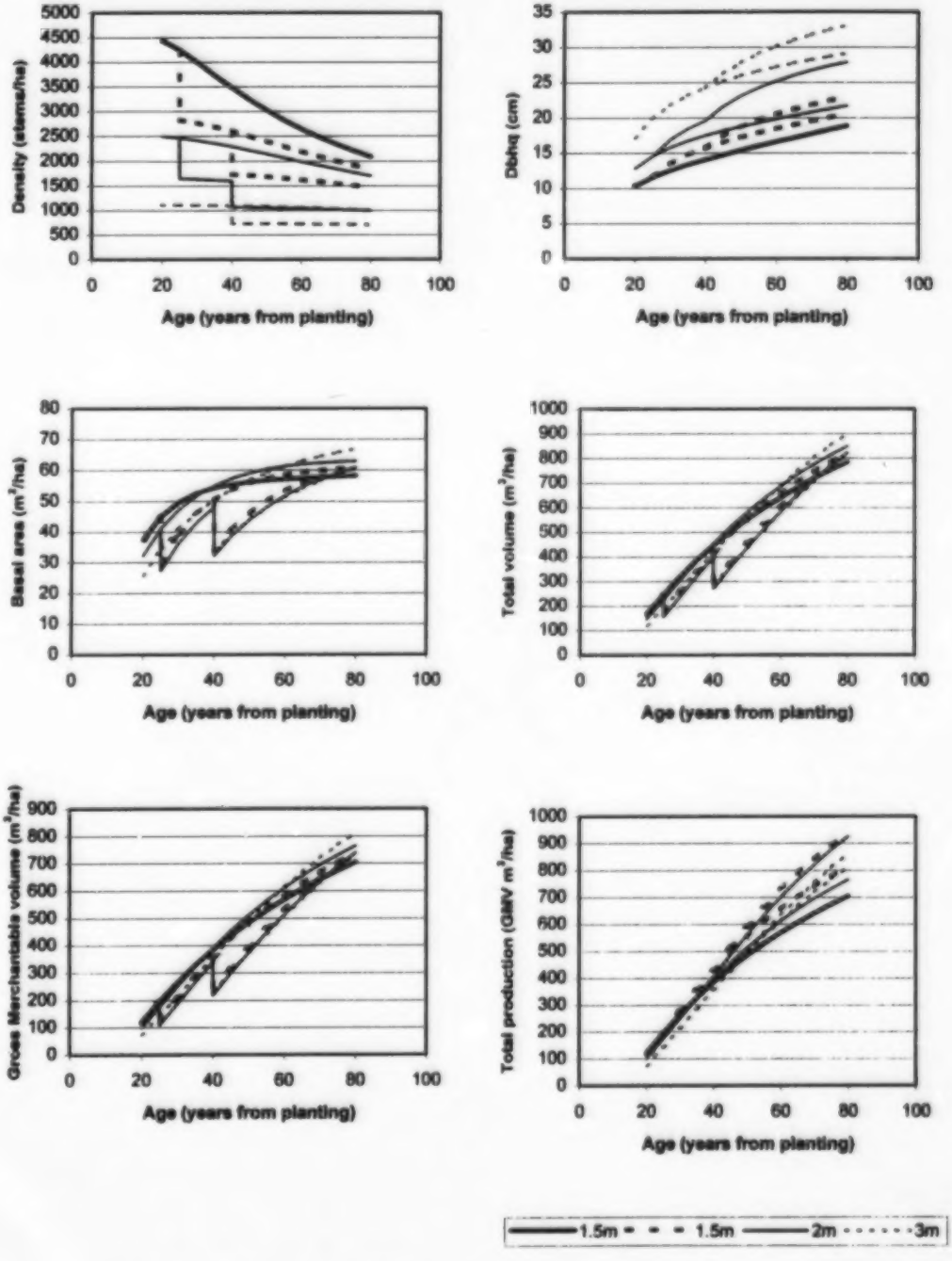


Figure 11. Predicted response to thinning for three initial spacings, 1.5m, 2m, and 3m.
The site index (m @ bh age 50 is 24.
High initial density thinned once at age 25 or at ages 25 and 40. Moderate initial density thinned at age 25 and 40. Low initial density at age 40.

M121

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Table 3. Predicted response to thinning for three initial spacings of 1.5m, 2m, and 3m.

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 24m @ 50 years breast-height age
Density: 4444, 2500, 1111 stems/ha

= indicates age of thinning

							GMV	PAI
	Topht	Density	Dbhq	BA	GTV	GMV	Total Prod	GMV
Age	(m)	(stems/ha)	(cm)	(m^2/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha/yr)
20	9.5	4444	10.4	37.4	167	119	119	
25	12.0	4240	11.6	45.1	247	195	195	15.1
30	14.3	3994	12.6	49.7	321	265	265	14.0
35	16.5	3734	13.4	52.6	388	328	328	12.7
40	18.6	3480	14.1	54.3	448	385	385	11.5
45	20.5	3241	14.8	55.4	503	437	437	10.4
50	22.3	3021	15.4	56.2	553	485	485	9.5
55	24.0	2823	16.0	56.7	599	529	529	8.7
60	25.6	2644	16.6	57.1	642	569	569	8.1
65	27.0	2483	17.2	57.4	682	606	606	7.5
70	28.4	2338	17.7	57.7	715	641	641	7.0
75	29.7	2208	18.3	58.0	753	674	674	6.6
80	30.9	2090	18.8	58.2	786	705	705	6.1

							GMV	PAI
	Topht	Density	Dbhq	BA	GTV	GMV	Total Prod	GMV
Age	(m)	(stems/ha)	(cm)	(m^2/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha/yr)
20	9.5	4444	10.4	37.4	167	119	119	
25	12.0	4240	11.6	45.1	247	195	195	15.1
30	14.3	2771	13.5	39.5	258	205	278	16.7
35	16.5	2695	14.7	45.9	341	284	357	15.7
40	18.6	2605	15.7	50.4	417	356	429	14.4
45	20.5	2507	16.5	53.5	486	422	494	13.1
50	22.3	2404	17.2	55.8	549	481	554	11.9
55	24.0	2301	17.8	57.3	606	535	607	10.7
60	25.6	2200	18.4	58.5	657	583	656	9.7
65	27.0	2103	19.0	59.3	703	627	700	8.8
70	28.4	2010	19.5	59.9	745	667	739	8.0
75	29.7	1923	20.0	60.4	784	703	776	7.3
80	30.9	1841	20.5	60.7	819	736	809	6.6

							GMV	PAI
	Topht	Density	Dbhq	BA	GTV	GMV	Total Prod	GMV
Age	(m)	(stems/ha)	(cm)	(m^2/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha/yr)
20	9.5	4444	10.4	37.4	167	119	119	
25	12.0	4240	11.6	45.1	247	195	195	15.1
30	14.3	2771	13.5	39.5	258	205	278	16.7
35	16.5	2695	14.7	45.9	341	284	357	15.7
40	18.6	2605	15.7	50.4	417	356	429	14.4
45	20.5	1715	17.4	40.7	374	315	514	17.1
50	22.3	1686	18.6	46.1	456	383	593	15.8
55	24.0	1657	19.6	50.1	532	484	684	14.3
60	25.6	1622	20.5	53.3	600	529	729	13.0
65	27.0	1585	21.2	55.8	662	588	788	11.8
70	28.4	1547	21.8	57.7	719	642	841	10.7
75	29.7	1507	22.4	59.3	770	690	890	9.7
80	30.9	1467	22.9	60.5	816	734	933	8.8

							GMV	PAI
	Topht	Density	Dbhq	BA	GTV	GMV	Total Prod	GMV
Age	(m)	(stems/ha)	(cm)	(m^2/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	2143	18.7	59.2	582	512	512	11.6
55	24.0	2065	19.3	60.4	637	564	564	10.5
60	25.6	1986	19.8	61.3	688	612	612	9.6
65	27.0	1913	20.3	62.0	734	656	656	8.7
70	28.4	1840	20.8	62.4	776	696	696	7.9
75	29.7	1770	21.3	62.8	814	732	732	7.2
80	30.9	1703	21.7	63.0	849	765	765	6.6

							GMV	PAI
	Topht	Density	Dbhq	BA	GTV	GMV	Total Prod	GMV
Age	(m)	(stems/ha)	(cm)	(m^2/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	1634	16.8	36.4	239	197	254	15.7
35	16.5	1619	18.4	43.1	321	265	331	15.5
40	18.6	1600	19.6	48.2	400	340	406	15.0
45	20.5	1062	21.6	38.8	357	299	486	16.1
50	22.3	1056	23.0	44.0	437	375	582	15.2
55	24.0	1049	24.2	48.3	513	446	634	14.3
60	25.6	1040	25.2	51.8	583	513	701	13.4
65	27.0	1030	26.0	54.7	650	576	764	12.5
70	28.4	1020	26.7	57.1	711	634	822	11.7
75	29.7	1008	27.3	59.2	769	689	876	10.9
80	30.9	996	27.9	60.9	822	739	927	10.1

							GMV	PAI
	Topht	Density	Dbhq	BA	GTV	GMV	Total Prod	GMV
Age	(m)	(stems/ha)	(cm)	(m^2/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha/yr)
20	9.5	1111	17.2	25.8	120	75	75	
25	12.0	1109	19.9	34.4	192	143	143	13.6
30	14.3	1105	21.7	41.0	267	214	214	14.3
35	16.5	1100	23.1	46.3	343	286	286	14.4
40	18.6	1093	24.2	50.5	418	357	357	14.1
45	20.5	1086	25.2	54.0	490	425	425	13.7
50	22.3	1077	25.9	56.9	560	491	491	13.2
55	24.0	1067	26.6	59.3	626	554	554	12.5
60	25.6	1056	27.2	61.4	689	613	613	11.8
65	27.0	1044	27.7	63.1	747	668	668	11.1
70	28.4	1032	28.2	64.6	802	720	720	10.4
75	29.7	1019	28.7	65.8	853	768	768	9.6
80	30.9	1005	29.1	66.8	900	813	813	8.9

							GMV	PAI
	Topht	Density	Dbhq	BA	GTV	GMV	Total Prod	GMV
Age	(m)	(stems/ha)	(cm)	(m^2/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha/yr)
20	9.5	1111	17.2	25.8	120	75	75	
25	12.0	1109	19.9	34.4	192	143	143	13.6
30	14.3	1105	21.7	41.0	267	214	214	14.3
35	16.5	1100	23.1	46.3	343	286	286	14.4
40	18.6	1093	24.2	50.5	418	357	357	14.1
45	20.5	727	26.2	39.4	362	304	430	14.8
50	22.3	725	27.8	44.0	437	375	502	14.2
55	24.0	723	29.1	47.9	509	443	570	13.6
60	25.6	720	30.1	51.3	578	506	635	13.0
65	27.0	717	31.0	54.1	643	570	699	12.5
70	28.4	713	31.8	56.6	705	628	755	11.7
75	29.7	709	32.5	58.7	763	683	810	11.0
80	30.9	705	33.1	60.6	817	736	862	10.4

Top Height = average height of the 100 largest diameter trees per hectare (m).
Density = stems per hectare.
Dbhq = stand quadratic mean diameter (cm).
BA = stand basal area (m^2) per hectare
GTV = gross total volume (m^3/ha).
GMV= gross merchantable volume (m^3/ha) (30cm stump height - 10cm upper diameter).
Total Prod = accumulated GMV volume (includes thinning volume) No mortality volume included.
PAI = periodic annual increment.

Table 3. Predicted response to thinning for three initial spacings of 1.5m, 2m, and 3m.

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	4444	10.4	37.4	167	119	119	
25	12.0	4240	11.6	45.1	247	195	195	15.1
30	14.3	3994	12.6	49.7	321	265	265	14.0
35	16.5	3734	13.4	52.6	388	328	328	12.7
40	18.6	3480	14.1	54.3	448	385	385	11.5
45	20.5	3241	14.9	55.4	503	437	437	10.4
50	22.3	3021	15.4	56.2	553	485	485	9.5
55	24.0	2823	16.0	56.7	599	528	528	8.7
60	25.6	2644	16.6	57.1	642	569	569	8.1
65	27.0	2483	17.2	57.4	682	606	606	7.5
70	28.4	2338	17.7	57.7	719	641	641	7.0
75	29.7	2208	18.3	58.0	753	674	674	6.6
80	30.9	2090	18.8	58.2	786	705	705	6.1

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 24m @ 50 years breast-height age
Density: 4444, 2500, 1111 stems/ha

= indicates age of thinning

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	4444	10.4	37.4	167	119	119	
25	12.0	4240	11.6	45.1	247	195	195	15.1
25	**12.0**	**3827**	**11.6**	**30.1**	**169**	**122**	**195**	**0.0**
30	14.3	2771	13.5	39.5	258	205	278	16.7
35	16.5	2695	14.7	45.9	341	284	357	15.7
40	18.6	2605	15.7	50.4	417	356	429	14.4
40	**18.6**	**1737**	**15.7**	**35.6**	**263**	**229**	**429**	**0.0**
45	20.5	1715	17.4	40.7	374	315	514	17.1
50	22.3	1688	18.6	46.1	456	393	593	15.6
55	24.0	1657	19.6	50.1	532	464	664	14.3
60	25.6	1622	20.5	53.3	600	529	729	13.0
65	27.0	1585	21.2	55.8	662	588	788	11.8
70	28.4	1547	21.8	57.7	719	642	841	10.7
75	29.7	1507	22.4	59.3	770	690	890	9.7
80	30.9	1467	22.9	60.5	816	734	933	8.8

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	2143	18.7	59.2	582	512	512	11.6
55	24.0	2065	19.3	60.4	637	564	564	10.5
60	25.6	1986	19.8	61.3	688	612	612	9.6
65	27.0	1913	20.3	62.0	734	656	656	8.7
70	28.4	1840	20.8	62.4	776	696	696	7.9
75	29.7	1770	21.3	62.8	814	732	732	7.2
80	30.9	1703	21.7	63.0	849	765	765	6.6

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
25	**12.0**	**1644**	**14.6**	**27.4**	**158**	**109**	**175**	**0.0**
30	14.3	1634	16.8	36.4	239	187	254	15.7
35	16.5	1619	18.4	43.1	321	265	331	15.5
40	18.6	1600	19.6	48.2	400	340	406	15.0
40	**18.6**	**1067**	**19.6**	**32.1**	**272**	**218**	**406**	**0.0**
45	20.5	1052	21.6	38.8	357	299	486	16.1
50	22.3	1056	23.0	44.0	437	375	562	15.2
55	24.0	1049	24.2	48.3	513	446	634	14.3
60	25.6	1040	25.2	51.8	583	513	701	13.4
65	27.0	1030	26.0	54.7	650	576	764	12.5
70	28.4	1020	26.7	57.1	711	634	822	11.7
75	29.7	1008	27.3	59.2	769	689	876	10.9
80	30.9	996	27.9	60.9	822	739	927	10.1

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	1111	17.2	25.8	120	75	75	
25	12.0	1109	19.9	34.4	192	143	143	13.6
30	14.3	1105	21.7	41.0	267	214	214	14.3
35	16.5	1100	23.1	46.3	343	286	286	14.4
40	18.6	1093	24.2	50.5	418	357	357	14.1
45	20.5	1086	25.2	54.0	490	425	425	13.7
50	22.3	1077	25.9	56.9	560	491	491	13.2
55	24.0	1067	26.6	59.3	626	554	554	12.5
60	25.6	1056	27.2	61.4	689	613	613	11.8
65	27.0	1044	27.7	63.1	747	668	668	11.1
70	28.4	1032	28.2	64.6	802	720	720	10.4
75	29.7	1019	28.7	65.8	853	768	768	9.6
80	30.9	1005	29.1	66.8	900	813	813	8.8

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	1111	17.2	25.8	120	75	75	
25	12.0	1109	19.9	34.4	192	143	143	13.6
30	14.3	1105	21.7	41.0	267	214	214	14.3
35	16.5	1100	23.1	46.3	343	286	286	14.4
40	18.6	1093	24.2	50.5	418	357	357	14.1
40	**18.6**	**729**	**24.2**	**33.7**	**284**	**230**	**357**	**0.0**
45	20.5	727	26.2	39.4	362	304	430	14.8
50	22.3	725	27.8	44.0	437	375	502	14.2
55	24.0	723	29.1	47.9	509	443	570	13.6
60	25.6	720	30.1	51.3	578	508	635	13.0
65	27.0	717	31.0	54.1	643	570	696	12.3
70	28.4	713	31.8	56.6	705	628	756	11.7
75	29.7	709	32.5	58.7	763	683	810	11.0
80	30.9	705	33.1	60.6	817	735	862	10.4

Top Height = average height of the 100 largest diameter trees per hectare (m).
Density = stems per hectare.
Dbhq = stand quadratic mean diameter (cm).
BA = stand basal area (m^2) per hectare.
GTV = gross total volume (m^3/ha).
GMV = gross merchantable volume (m^3/ha) (30cm stump height - 10cm upper diameter).
Total Prod = accumulated GMV volume (includes thinning volume) No mortality volume included.
PAI = periodic annual increment.

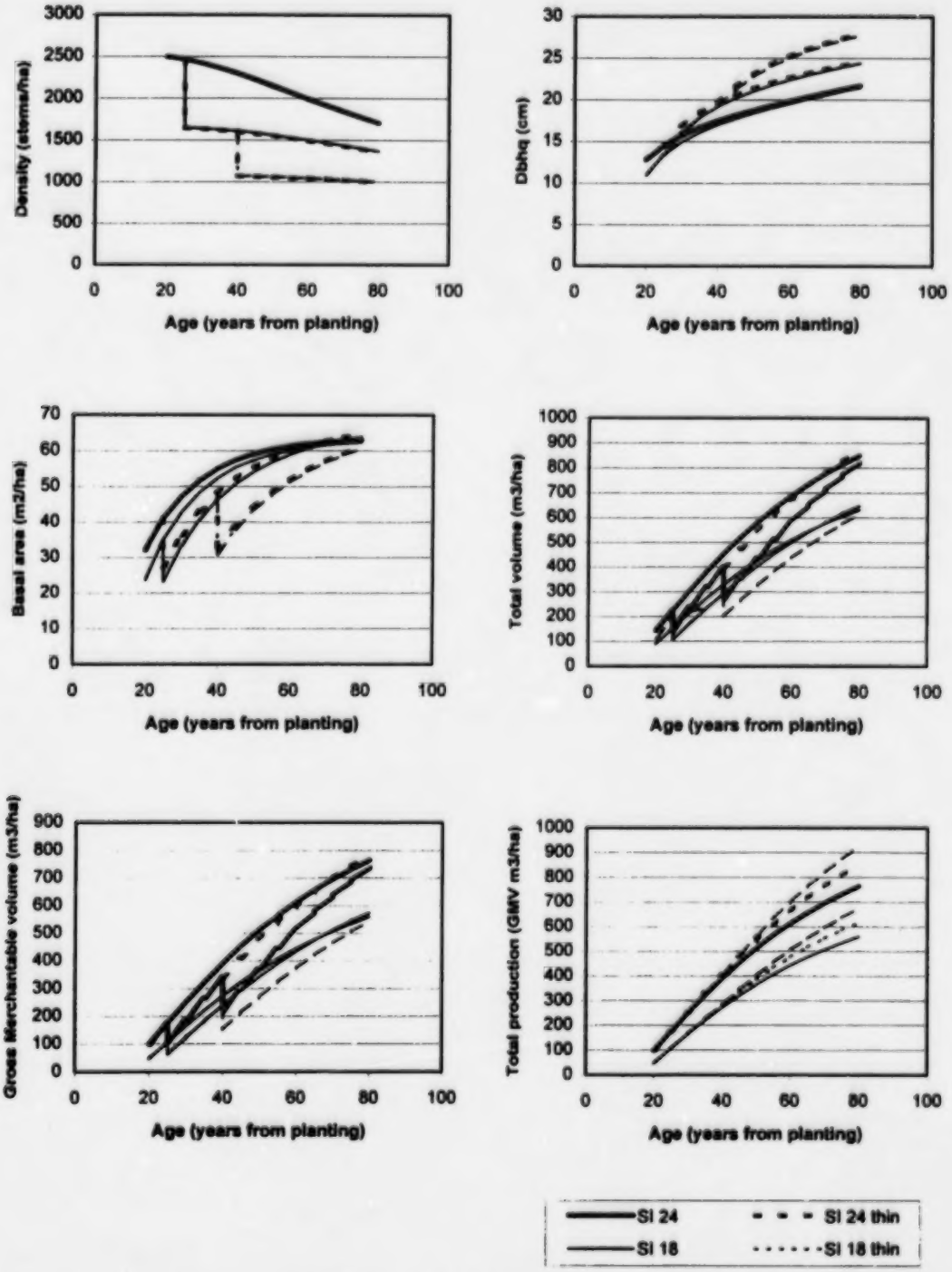

Figure 12. Predicted response to thinning for site index 18 and 24 (m @ bh age 50). Thinning ages are 25 0r 25 and 40.

Table 4. Predicted response to thinning for site index 18 and 24 (m @ bh age 50).

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 18 & 24m @50 yrs breast-height
Density: 2500 stems/ha

= indicates age of thinning

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	7.3	2500	11.0	23.8	90	46	46	
25	9.1	2473	13.4	35.0	153	106	106	11.9
30	10.8	2431	15.0	42.9	215	165	165	11.8
35	12.5	2376	16.1	48.4	275	221	221	11.3
40	14.0	2311	17.0	52.4	330	274	274	10.5
45	15.4	2239	17.7	55.3	381	322	322	9.7
50	16.8	2163	18.4	57.4	428	367	367	8.9
55	18.0	2085	19.0	59.0	471	407	407	8.1
60	19.2	2007	19.5	60.1	509	443	443	7.3
65	20.2	1931	20.1	61.0	544	477	477	6.6
70	21.2	1857	20.5	61.8	576	507	507	6.0
75	22.2	1786	21.0	62.0	605	534	534	5.5
80	23.0	1718	21.5	62.3	632	559	559	5.0

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.8	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	2143	18.7	59.2	582	512	512	11.6
55	24.0	2065	19.3	60.4	637	564	564	10.5
60	25.6	1988	19.8	61.3	688	612	612	9.6
65	27.0	1913	20.3	62.0	734	656	656	8.7
70	28.4	1840	20.8	62.4	776	696	696	7.9
75	29.7	1770	21.3	62.8	814	732	732	7.2
80	30.9	1703	21.7	63.0	849	765	765	6.6

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	7.3	2500	11.0	23.8	90	46	46	
25	9.1	2473	13.4	35.0	153	106	106	11.9
30	10.9	1640	16.1	33.4	171	123	166	12.1
35	12.5	1626	17.9	40.8	234	183	226	11.9
40	14.0	1608	19.2	46.4	294	240	283	11.4
45	15.4	1586	20.2	50.7	351	293	337	10.8
50	16.8	1560	21.0	54.1	404	344	387	10.1
55	18.0	1531	21.7	56.8	454	391	434	9.4
60	19.2	1501	22.4	58.9	499	434	477	8.6
65	20.2	1468	22.9	60.6	541	474	517	7.9
70	21.2	1435	23.4	62.0	580	510	553	7.3
75	22.2	1401	23.9	63.0	615	543	587	6.6
80	23.0	1367	24.4	63.9	647	574	617	6.1

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.8	41.0	226	175	175	15.1
30	14.3	1634	16.8	36.4	239	187	254	15.7
35	16.5	1619	18.4	43.1	321	265	331	15.5
40	18.6	1600	19.6	48.2	400	340	406	15.0
45	20.5	1578	20.5	52.2	475	411	477	14.2
50	22.3	1552	21.3	55.3	545	477	544	13.3
55	24.0	1523	22.0	57.8	611	539	606	12.4
60	25.6	1493	22.6	59.8	672	597	663	11.5
65	27.0	1461	23.1	61.4	727	650	718	10.6
70	28.4	1428	23.6	62.6	779	698	764	9.7
75	29.7	1394	24.1	63.6	826	742	809	8.9
80	30.9	1360	24.6	64.4	868	780	849	8.1

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	7.3	2500	11.0	23.8	112	46	46	
25	9.1	2473	13.4	35.0	195	106	108	11.9
30	10.9	1640	16.1	33.4	220	123	166	12.1
35	12.5	1626	17.9	40.8	234	183	226	11.9
40	14.0	1608	19.2	46.4	294	240	283	11.4
45	15.4	1067	21.2	37.8	266	213	344	12.2
50	16.8	1061	22.8	43.2	326	270	401	11.5
55	18.0	1053	24.0	47.8	383	324	455	10.8
60	19.2	1045	25.0	51.2	436	374	505	10.1
65	20.2	1035	25.8	54.2	486	421	552	9.4
70	21.2	1024	26.5	56.7	532	465	596	8.7
75	22.2	1013	27.2	58.8	575	505	636	8.1
80	23.0	1001	27.8	60.6	614	543	674	7.5

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.8	41.0	226	175	175	15.1
30	14.3	1634	16.8	36.4	239	187	254	15.7
35	16.5	1619	18.4	43.1	321	265	331	15.5
40	18.6	1600	19.6	48.2	400	340	406	15.0
45	20.5	1082	21.6	38.8	357	299	488	16.1
50	22.3	1058	23.0	44.0	437	375	562	15.2
55	24.0	1049	24.2	48.3	513	446	634	14.3
60	25.6	1040	25.2	51.8	585	513	701	13.4
65	27.0	1030	26.0	54.7	650	576	764	12.5
70	28.4	1020	26.7	57.1	711	634	822	11.7
75	29.7	1008	27.3	59.2	769	689	876	10.9
80	30.9	996	27.9	60.9	822	739	927	10.1

Table 4. Predicted response to thinning for site index 18 and 24 (m @ bh age 50).

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 18 & 24m @50 yrs breast-height
Density: 2500 stems/ha

= indicates age of thinning

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	7.3	2500	11.0	23.8	90	46	46	
25	9.1	2473	13.4	35.0	153	106	106	11.9
30	10.9	2431	15.0	42.9	215	165	165	11.8
35	12.5	2376	16.1	48.4	275	221	221	11.3
40	14.0	2311	17.0	52.4	330	274	274	10.5
45	15.4	2239	17.7	55.3	381	322	322	9.7
50	16.8	2163	18.4	57.4	428	367	367	8.9
55	18.0	2085	19.0	59.0	471	407	407	8.1
60	19.2	2007	19.5	60.1	509	443	443	7.3
65	20.2	1931	20.1	61.0	544	477	477	6.6
70	21.2	1857	20.6	61.6	576	507	507	6.0
75	22.2	1786	21.0	62.0	605	534	534	5.5
80	23.0	1718	21.5	62.3	632	559	559	5.0

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	2143	18.7	59.2	582	512	512	11.6
55	24.0	2065	19.3	60.4	637	564	564	10.5
60	25.6	1988	19.8	61.3	688	612	612	9.6
65	27.0	1913	20.3	62.0	734	656	656	8.7
70	28.4	1840	20.8	62.4	776	696	696	7.9
75	29.7	1770	21.3	62.8	814	732	732	7.2
80	30.9	1703	21.7	63.0	849	765	765	6.6

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	7.3	2500	11.0	23.8	90	46	46	
25	9.1	2473	13.4	35.0	153	106	106	11.9
25	**9.1**	**1849**	**13.4**	**23.4**	**107**	**63**	**106**	**0.0**
30	10.9	1640	16.1	33.4	171	123	166	12.1
35	12.5	1626	17.9	40.8	234	183	226	11.9
40	14.0	1608	19.2	46.4	294	240	283	11.4
45	15.4	1585	20.2	50.7	351	293	337	10.8
50	16.8	1560	21.0	54.1	404	344	387	10.1
55	18.0	1531	21.7	56.8	454	391	434	9.4
60	19.2	1501	22.4	58.9	499	434	477	8.6
65	20.2	1468	22.9	60.6	541	474	517	7.9
70	21.2	1435	23.4	62.0	580	510	553	7.3
75	22.2	1401	23.9	63.0	615	543	587	6.6
80	23.0	1367	24.4	63.9	647	574	617	6.1

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
25	**12.0**	**1844**	**14.6**	**27.4**	**156**	**109**	**175**	**0.0**
30	14.3	1634	16.8	36.4	239	187	254	15.7
35	16.5	1619	18.4	43.1	321	265	331	15.5
40	18.6	1600	19.6	48.2	400	340	406	15.0
45	20.5	1578	20.5	52.2	475	411	477	14.2
50	22.3	1552	21.3	55.3	545	477	544	13.3
55	24.0	1523	22.0	57.8	611	539	606	12.4
60	25.6	1493	22.6	59.8	672	597	663	11.5
65	27.0	1461	23.1	61.4	727	650	716	10.6
70	28.4	1428	23.6	62.6	779	698	764	9.7
75	29.7	1394	24.1	63.6	826	742	809	8.9
80	30.9	1360	24.6	64.4	868	783	849	8.1

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	7.3	2500	11.0	23.8	112	46	46	
25	9.1	2473	13.4	35.0	195	106	106	11.9
25	**9.1**	**1849**	**13.4**	**23.4**	**135**	**63**	**106**	**0.0**
30	10.9	1640	16.1	33.4	220	123	166	12.1
35	12.5	1626	17.9	40.8	234	183	226	11.9
40	14.0	1608	19.2	46.4	294	240	283	11.4
40	**14.0**	**1072**	**19.2**	**30.9**	**201**	**152**	**283**	**0.0**
45	15.4	1067	21.2	37.8	268	213	344	12.2
50	16.8	1061	22.8	43.2	326	270	401	11.5
55	18.0	1053	24.0	47.6	383	324	455	10.8
60	19.2	1045	25.0	51.2	436	374	505	10.1
65	20.2	1035	25.8	54.2	486	421	552	9.4
70	21.2	1024	26.5	56.7	532	465	596	8.7
75	22.2	1013	27.2	58.8	575	505	636	8.1
80	23.0	1001	27.8	60.6	614	543	674	7.5

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
25	**12.0**	**1844**	**14.6**	**27.4**	**156**	**109**	**175**	**0.0**
30	14.3	1634	16.8	36.4	239	187	254	15.7
35	16.5	1619	18.4	43.1	321	265	331	15.5
40	18.6	1600	19.6	48.2	400	340	406	15.0
40	**18.6**	**1067**	**19.6**	**32.1**	**272**	**219**	**406**	**0.0**
45	20.5	1062	21.6	38.8	357	299	486	16.1
50	22.3	1056	23.0	44.0	437	375	562	15.2
55	24.0	1049	24.2	48.3	513	446	634	14.3
60	25.6	1040	25.2	51.8	583	513	701	13.4
65	27.0	1030	26.0	54.7	650	576	764	12.5
70	28.4	1020	26.7	57.1	711	634	822	11.7
75	29.7	1008	27.3	59.2	769	689	876	10.9
80	30.9	996	27.9	60.9	822	739	927	10.1

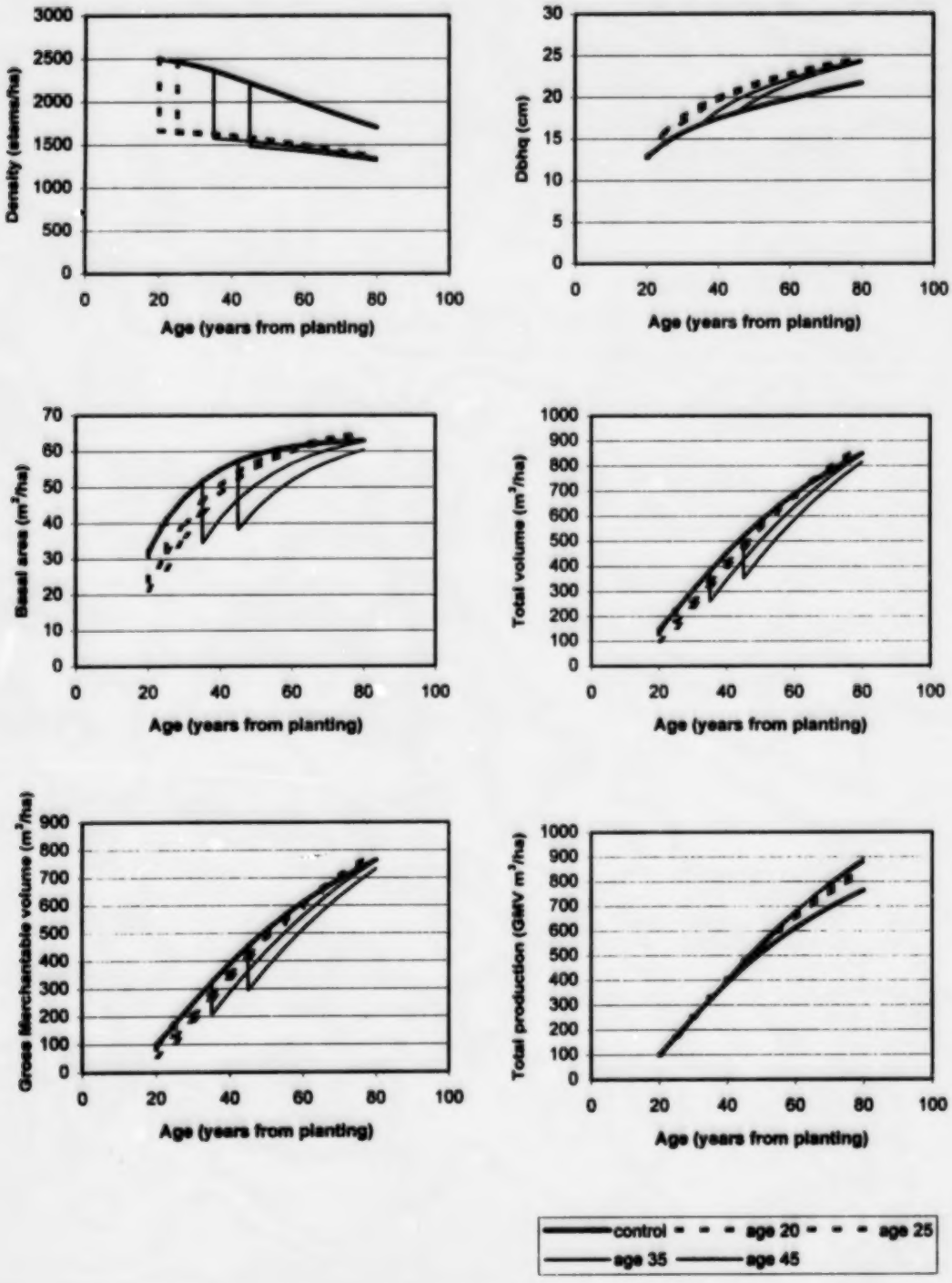

Figure 13. Predicted response to thinning for site index 24 (m @ bh age 50) stand. Thinning represents a 33% depletion at all ages.

Table 5. Predicted response to timing of thinning for a site index (m @ bh age 50) stand.

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	2143	18.7	59.2	582	512	512	11.6
55	24.0	2065	19.3	60.4	637	564	564	10.5
60	25.6	1988	19.8	61.3	686	612	612	9.6
65	27.0	1912	20.3	62.0	734	658	656	8.7
70	28.4	1839	20.8	62.4	776	696	696	7.9
75	29.7	1769	21.3	62.8	814	732	732	7.2
80	30.9	1703	21.7	63.0	849	765	765	6.6

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 24m @ 50 years breast-height age
Density: **2500** stems/ha

= indicates age of thinning

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	1889	15.7	32.1	190	132	173	14.7
30	14.3	1846	17.6	40.0	261	208	249	15.3
35	16.5	1831	18.9	46.0	341	284	325	15.1
40	18.6	1811	20.0	50.5	418	357	398	14.6
45	20.5	1786	20.8	54.1	491	426	467	13.9
50	22.3	1759	21.6	56.9	560	491	533	13.0
55	24.0	1730	22.2	59.2	624	552	593	12.1
60	25.6	1699	22.8	60.9	684	606	649	11.2
65	27.0	1665	23.3	62.3	739	660	701	10.3
70	28.4	1631	23.8	63.5	789	708	749	9.5
75	29.7	1597	24.2	64.3	834	751	792	8.7
80	30.9	1563	24.6	65.0	878	790	832	7.9

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	1634	16.8	36.4	239	187	254	15.7
35	16.5	1619	18.4	43.1	321	265	331	15.5
40	18.6	1600	19.6	48.2	400	340	406	14.9
45	20.5	1578	20.5	52.2	475	410	477	14.2
50	22.3	1552	21.3	55.3	545	477	543	13.3
55	24.0	1523	22.0	57.8	611	539	606	12.4
60	25.6	1493	22.6	59.8	672	597	665	11.5
65	27.0	1460	23.1	61.4	727	650	716	10.6
70	28.4	1427	23.6	62.6	779	698	764	9.7
75	29.7	1394	24.1	63.6	826	742	809	8.9
80	30.9	1360	24.6	64.4	868	783	849	8.1

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	1569	18.4	41.4	348	288	404	18.2
45	20.5	1541	19.6	48.7	426	365	480	15.3
50	22.3	1519	20.6	50.8	502	438	552	14.3
55	24.0	1494	21.5	54.1	572	503	618	13.3
60	25.6	1467	22.2	56.6	637	564	679	12.3
65	27.0	1438	22.9	58.7	696	620	736	11.3
70	28.4	1407	23.4	60.4	751	672	787	10.3
75	29.7	1376	23.9	61.7	801	719	835	9.4
80	30.9	1344	24.4	62.8	846	762	878	8.6

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	1493	19.6	44.0	437	375	534	16.0
55	24.0	1444	20.7	48.5	514	448	607	14.7
60	25.6	1421	21.6	52.0	586	518	675	13.5
65	27.0	1396	22.4	54.8	651	577	737	12.4
70	28.4	1370	23.0	57.1	711	634	793	11.3
75	29.7	1343	23.6	58.9	765	685	845	10.3
80	30.9	1315	24.2	60.4	815	732	892	9.4

Topht = average height of the 100 largest diameter trees per hectare (m).
Density = stems per hectare.
Dbhq = stand quadratic mean diameter (cm).
BA = stand basal area (m^2) per hectare
GTV = gross total volume (m^3/ha).
GMV = gross merchantable volume (m^3/ha) (between a 30 cm stump height and 10 cm upper stem diameter).
Total Prod = accumulated GMV production (includes extracted thinning volume -- Does not include mortality volume).
PAI = periodic annual increment.

Table 5. Predicted response to timing of thinning for a site index (m @ bh age 50) stand.

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	2143	18.7	59.2	582	512	512	11.6
55	24.0	2065	19.3	60.4	637	564	564	10.5
60	25.6	1988	19.8	61.3	688	612	612	9.6
65	27.0	1912	20.3	62.0	734	656	656	8.7
70	28.4	1839	20.8	62.4	776	696	696	7.9
75	29.7	1769	21.3	62.8	814	732	732	7.2
80	30.9	1703	21.7	63.0	849	765	765	6.6

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 24m @ 50 years breast-height age
Density: 2500 stems/ha

= indicates age of thinning

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	2143	18.7	59.2	582	512	512	11.6
55	24.0	2065	19.3	60.4	637	564	564	10.5
60	25.6	1988	19.8	61.3	688	612	612	9.6
65	27.0	1912	20.3	62.0	734	656	656	8.7
70	28.4	1839	20.8	62.4	776	696	696	7.9
75	29.7	1769	21.3	62.8	814	732	732	7.2
80	30.9	1703	21.7	63.0	849	765	765	6.6

Thinning intensity

Thinning intensity and number of thinnings had little effect on total production (Figure 14 and Table 6, Figure 15 and Table 7). However, the effect on d_g and therefore product is significant. As well, thinning intensity and the number of thinnings have a large impact on the economics of an operation.

Type of thinning (row vs. selection)

The models used here assume a regular (average or row) thinning, i.e., the thinning does not affect the d_g. However, more realistic predictions are possible if the post thinning d_g (or basal area) and stem numbers are known. Coffman (1976) and Leichty *et al.* (1986) noted a smaller diameter growth response following thinning for a row thinning compared to a thinning that selectively removed the smaller stems (thinning from below). This smaller growth response from the row thinnings was attributed to the retention of smaller, inferior trees with a below average thinning response and the removal of some of the best performers. The smaller growth response may also be due to the clumped arrangement of the residual stems (in rows).

A more uniform arrangement of the residual stands would encourage symmetric crown development and likely result in more complete crown closure sooner than a row thinning. However, results from British Columbia indicate that uniform spacing is not as important as encouraging the growth of trees with good height growth (Mitchell and Goudie 1998). They conclude it is best to remove short, slow growing trees without creating large openings that will remain unoccupied for a long time.

Cooley (1969) found that in the fifteen years after thinning, diameter growth was largely independent of whether the trees were thinned from below or as a crown release. Stiell (1978) found lower dbh growth and basal area per hectare growth in clumped vs. uniformly spaced plantations. However, there were no significant differences in volume per hectare.

Stiell (1960) found that removing every third row in a 20 year old plantation (1.8m spacing) did not result in enough sweep to degrade the value of the tree.

Discussion

Overall, thinning within the range of conditions in this study does not appear to increase overall volume produced. This is in agreement with Langsaeter's hypothesis as expressed in Smith (1962).

The total production of cubic volume by a stand of given age and composition on a given site is, for all practical purposes, constant and optimum for a wide range of density of stocking. It can be decreased, but not increased, by altering the amount of growing stock to levels outside this range.

Thinnings designed to anticipate losses of volume through natural suppression represent the only reliable method of maximizing volume yields from a stand.

In his review of spacing studies, Evert (1971) found that in almost all spacing experiments, the total volume production decreased with increasing initial spacing while the merchantable volume sometimes decreased and sometimes increased. Leichty *et al.* (1986) found no significant differences between total production 10 years following thinning of good site quality red pine (residual levels: 13.8m²/ha to 36.8m²/ha). Rudolph *et al.* (1984) found volume production of red pine declined with thinning intensity. Amateis *et al.* (1996) found thinning had a negative effect on total production in loblolly pine but the sawlog yield was greater on thinned plots. Mitchell and Goudie (1998) found commercial thinning in British Columbia did not increase the total volume harvested but could be useful in shortening the rotation length to alleviate

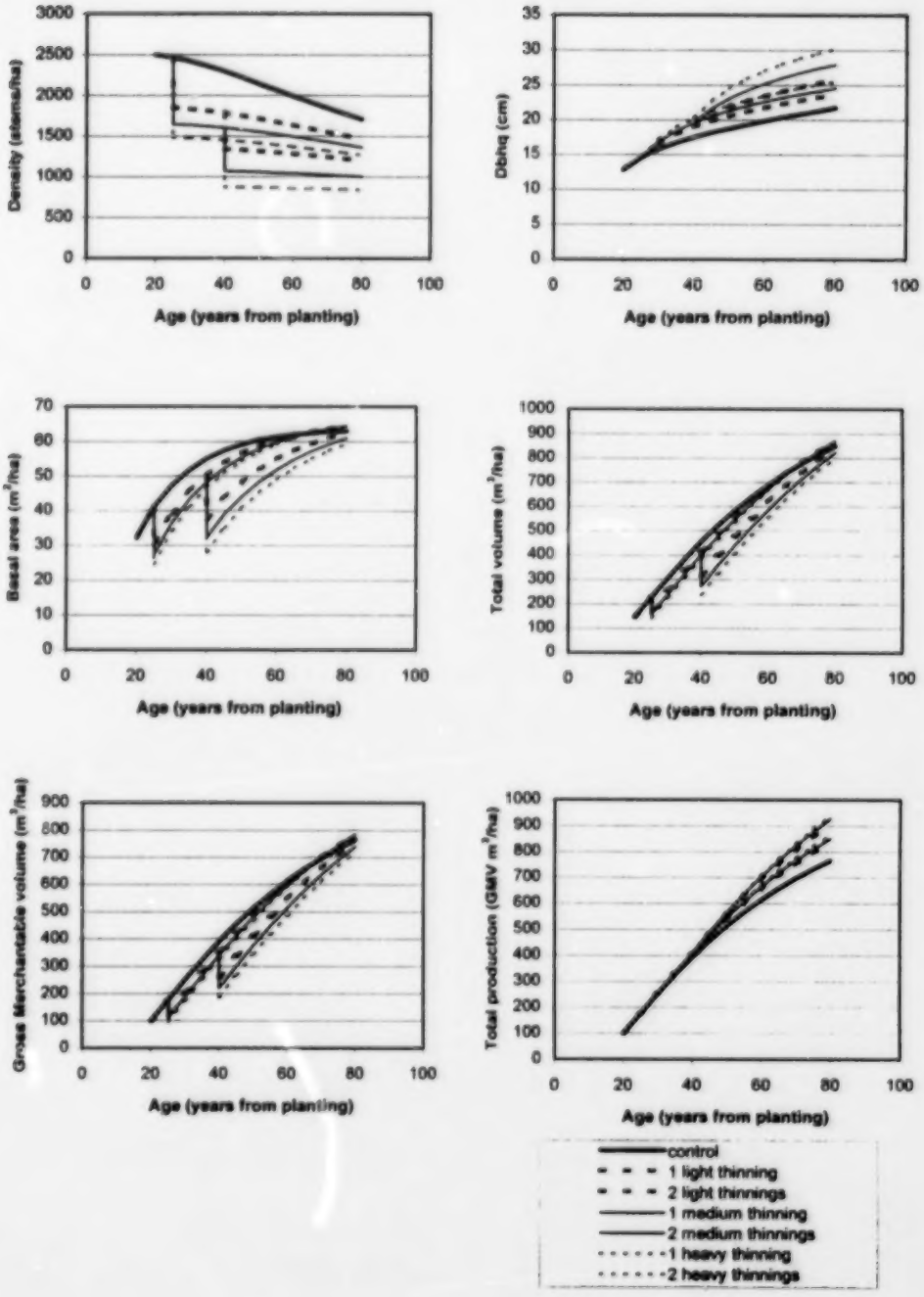

Figure 14. Predicted response to three thinning level intensities and number of thinnings for site index 24 (m @ bh age 50) stand.

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Table 6. Predicted response to three thinning level intensities and number of thinnings for a site index 24m stand.

Age	Top Height (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2487	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	2143	18.7	59.2	582	512	512	11.6
55	24.0	2065	19.3	60.4	637	564	564	10.5
60	25.6	1988	19.8	61.3	686	612	612	9.6
65	27.0	1913	20.3	62.0	734	656	656	8.7
70	28.4	1840	20.8	62.4	778	696	696	7.9
75	29.7	1770	21.3	62.8	814	732	732	7.2
80	30.9	1703	21.7	63.0	849	765	765	6.5

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 24m @ 50 years breast-height age
Density: 2500 stems/ha

= indicates age of thinning

Age	Top Height (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2487	14.6	41.0	226	175	175	15.1
30	14.3	1834	16.5	39.2	256	204	253	15.7
35	16.5	1812	17.9	45.4	337	280	330	15.4
40	18.6	1784	18.9	50.1	415	354	404	14.7
45	20.5	1752	19.6	53.8	488	423	473	13.9
50	22.3	1715	20.5	56.6	557	486	536	13.0
55	24.0	1676	21.1	58.7	620	548	598	12.0
60	25.6	1635	21.7	60.4	678	603	653	11.0
65	27.0	1593	22.2	61.8	732	654	703	10.1
70	28.4	1550	22.7	62.8	780	700	749	9.2
75	29.7	1507	23.2	63.6	825	742	791	8.4
80	30.9	1465	23.6	64.2	865	780	829	7.6

Age	Top Height (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2487	14.6	41.0	226	175	175	15.1
30	14.3	1834	16.5	39.2	256	204	253	15.7
35	16.5	1812	17.9	45.4	337	280	330	15.4
40	18.6	1784	18.9	50.1	415	354	404	14.7
45	20.5	1327	20.4	43.5	388	339	482	15.7
50	22.3	1314	21.6	48.1	476	412	566	14.8
55	24.0	1299	22.5	51.8	549	481	625	13.6
60	25.6	1281	23.3	54.8	617	545	689	12.9
65	27.0	1262	24.0	57.3	680	604	749	11.9
70	28.4	1242	24.7	59.3	738	659	804	11.0
75	29.7	1221	25.2	60.9	791	710	854	10.1
80	30.9	1199	25.7	62.3	840	756	900	9.2

Age	Top Height (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2487	14.6	41.0	226	175	175	15.1
30	14.3	1834	16.8	38.4	239	187	254	15.7
35	16.5	1819	18.4	43.1	321	285	331	15.5
40	18.6	1800	19.6	46.2	400	340	406	15.0
45	20.5	1578	20.5	52.2	475	411	477	14.2
50	22.3	1552	21.3	55.3	545	477	544	13.3
55	24.0	1523	22.0	57.8	611	539	606	12.4
60	25.6	1493	22.6	59.8	672	597	663	11.5
65	27.0	1461	23.1	61.4	727	650	716	10.6
70	28.4	1428	23.6	62.6	779	698	764	9.7
75	29.7	1394	24.1	63.6	826	742	809	8.9
80	30.9	1360	24.6	64.4	869	783	849	8.1

Age	Top Height (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2487	14.6	41.0	226	175	175	15.1
30	14.3	1834	16.8	38.4	239	187	254	15.7
35	16.5	1819	18.4	43.1	321	285	331	15.5
40	18.6	1800	19.6	46.2	400	340	406	15.0
45	20.5	1662	21.6	38.6	357	299	486	16.1
50	22.3	1668	23.0	44.0	437	375	562	15.2
55	24.0	1649	24.2	48.3	513	448	634	14.3
60	25.6	1640	25.2	51.8	583	513	701	13.4
65	27.0	1630	26.0	54.7	650	576	764	12.5
70	28.4	1620	26.7	57.1	711	634	822	11.7
75	29.7	1609	27.3	58.2	769	689	876	10.9
80	30.9	1595	27.9	59.8	822	739	927	10.1

Age	Top Height (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2487	14.6	41.0	226	175	175	15.1
30	14.3	1473	17.2	34.0	224	174	253	15.6
35	16.5	1460	18.9	41.1	307	251	331	15.6
40	18.6	1449	20.2	46.5	386	327	407	15.1
45	20.5	1433	21.2	50.6	462	399	479	14.4
50	22.3	1414	22.1	54.2	534	467	548	13.6
55	24.0	1393	22.8	56.9	601	530	610	12.7
60	25.6	1369	23.4	59.1	664	590	669	11.8
65	27.0	1345	24.0	60.9	722	644	724	11.0
70	28.4	1319	24.5	62.4	775	695	775	10.1
75	29.7	1293	25.0	63.5	824	741	821	9.3
80	30.9	1266	25.5	64.5	869	784	865	8.5

Age	Top Height (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	148	99	99	
25	12.0	2487	14.6	41.0	226	175	175	15.1
30	14.3	1473	17.2	34.0	224	174	253	15.6
35	16.5	1460	18.9	41.1	307	251	331	15.6
40	18.6	1449	20.2	46.5	386	327	407	15.1
45	20.5	987	22.7	35.0	323	287	487	16.1
50	22.3	994	24.5	42.6	404	344	564	15.4
55	24.0	980	25.9	48.2	481	418	638	14.6
60	25.6	964	27.0	52.6	553	488	708	13.7
65	27.0	961	28.0	56.2	621	548	769	12.6
70	28.4	945	28.8	58.8	680	610	830	12.1
75	29.7	939	29.5	57.3	745	666	886	11.3
80	30.9	930	30.1	59.3	801	719	938	10.5

Top Height = average height of the 100 largest diameter trees per hectare (m).
Density = stems per hectare.
Dbhq = stand quadratic mean diameter (cm).
BA = stand basal area (m^2) per hectare
GTV = gross total volume (m^3/ha).
GMV= gross merchantable volume (m^3/ha) (30 cm stump height - 10 cm upper diameter).
Total Prod = accumulated GMV volume (includes thinning volume) No mortality volume included.
PAI = periodic annual increment.

Table 6. Predicted response to three thinning level intensities and number of thinnings for a site index 24m stand.

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	2419	15.8	47.3	305	250	250	15.1
35	16.5	2361	16.7	51.8	382	323	323	14.5
40	18.6	2293	17.5	55.0	454	391	391	13.6
45	20.5	2220	18.1	57.4	521	454	454	12.6
50	22.3	2143	18.7	59.2	582	512	512	11.6
55	24.0	2065	19.3	60.4	637	564	564	10.5
60	25.6	1988	19.8	61.3	688	612	612	9.6
65	27.0	1913	20.3	62.0	734	656	656	8.7
70	28.4	1840	20.8	62.4	776	696	696	7.9
75	29.7	1770	21.3	62.8	814	732	732	7.2
80	30.9	1703	21.7	63.0	849	765	765	6.6

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 24m @ 50 years breast-height age
Density: **2500** stems/ha

= indicates age of thinning

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	1834	16.5	39.2	256	204	253	15.7
35	16.5	1812	17.9	48.4	337	280	330	15.4
40	18.6	1784	18.9	50.1	415	354	404	14.7
45	20.5	1752	19.8	53.8	486	423	473	13.9
50	22.3	1715	20.5	56.6	557	488	538	13.0
55	24.0	1676	21.1	58.7	620	548	598	12.0
60	25.6	1636	21.7	60.4	678	603	653	11.0
65	27.0	1593	22.2	61.8	732	654	703	10.1
70	28.4	1550	22.7	62.8	780	700	749	9.2
75	29.7	1507	23.2	63.6	825	742	791	8.4
80	30.9	1465	23.6	64.2	865	780	829	7.6

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	1634	16.8	36.4	239	187	254	15.7
35	16.5	1619	18.4	43.1	321	265	331	15.5
40	18.6	1600	19.6	48.2	400	340	406	15.0
45	20.5	1578	20.5	52.2	475	411	477	14.2
50	22.3	1552	21.3	55.3	545	477	544	13.3
55	24.0	1523	22.0	57.8	611	539	606	12.4
60	25.6	1493	22.6	59.8	672	597	663	11.5
65	27.0	1461	23.1	61.4	727	650	716	10.6
70	28.4	1428	23.6	62.6	779	698	764	9.7
75	29.7	1394	24.1	63.6	826	742	809	8.9
80	30.9	1360	24.6	64.4	868	783	849	8.1

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	1473	17.2	34.0	224	174	253	15.6
35	16.5	1483	18.9	41.1	307	251	331	15.6
40	18.6	1449	20.2	46.5	386	327	407	15.1
45	20.5	1433	21.2	50.8	462	399	478	14.4
50	22.3	1414	22.1	54.2	534	467	546	13.6
55	24.0	1393	22.8	56.9	601	530	610	12.7
60	25.6	1369	23.4	59.1	664	590	669	11.8
65	27.0	1345	24.0	60.9	722	644	724	11.0
70	28.4	1319	24.5	62.4	775	695	775	10.1
75	29.7	1293	25.0	63.5	824	741	821	9.3
80	30.9	1266	25.5	64.5	869	784	863	8.5

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.9	32.2	148	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	1473	17.2	34.0	224	174	253	15.6
35	16.5	1483	18.9	41.1	307	251	331	15.6
40	18.6	1449	20.2	46.5	386	327	407	15.1
45	20.5	867	22.7	35.0	323	267	487	16.1
50	22.3	864	24.5	40.6	404	344	564	15.4
55	24.0	860	25.9	45.2	481	418	636	14.5
60	25.6	856	27.0	49.0	553	485	705	13.7
65	27.0	851	28.0	52.2	621	549	769	12.9
70	28.4	845	28.8	55.0	685	610	830	12.1
75	29.7	839	29.5	57.3	745	668	886	11.3
80	30.9	832	30.1	59.3	801	719	939	10.5

Top Height = average height of the 100 largest diameter trees per hectare (m)
Density = stems per hectare
Dbhq = stand quadratic mean diameter (cm)
BA = stand basal area (m^2) per hectare

GTV = gross total volume (m^3/ha)
GMV = gross merchantable volume (m^3/ha) (30 cm stump height - 10 cm upper diameter)
Total Prod = accumulated GMV volume (includes thinning volume) No mortality volume included
PAI = periodic annual increment

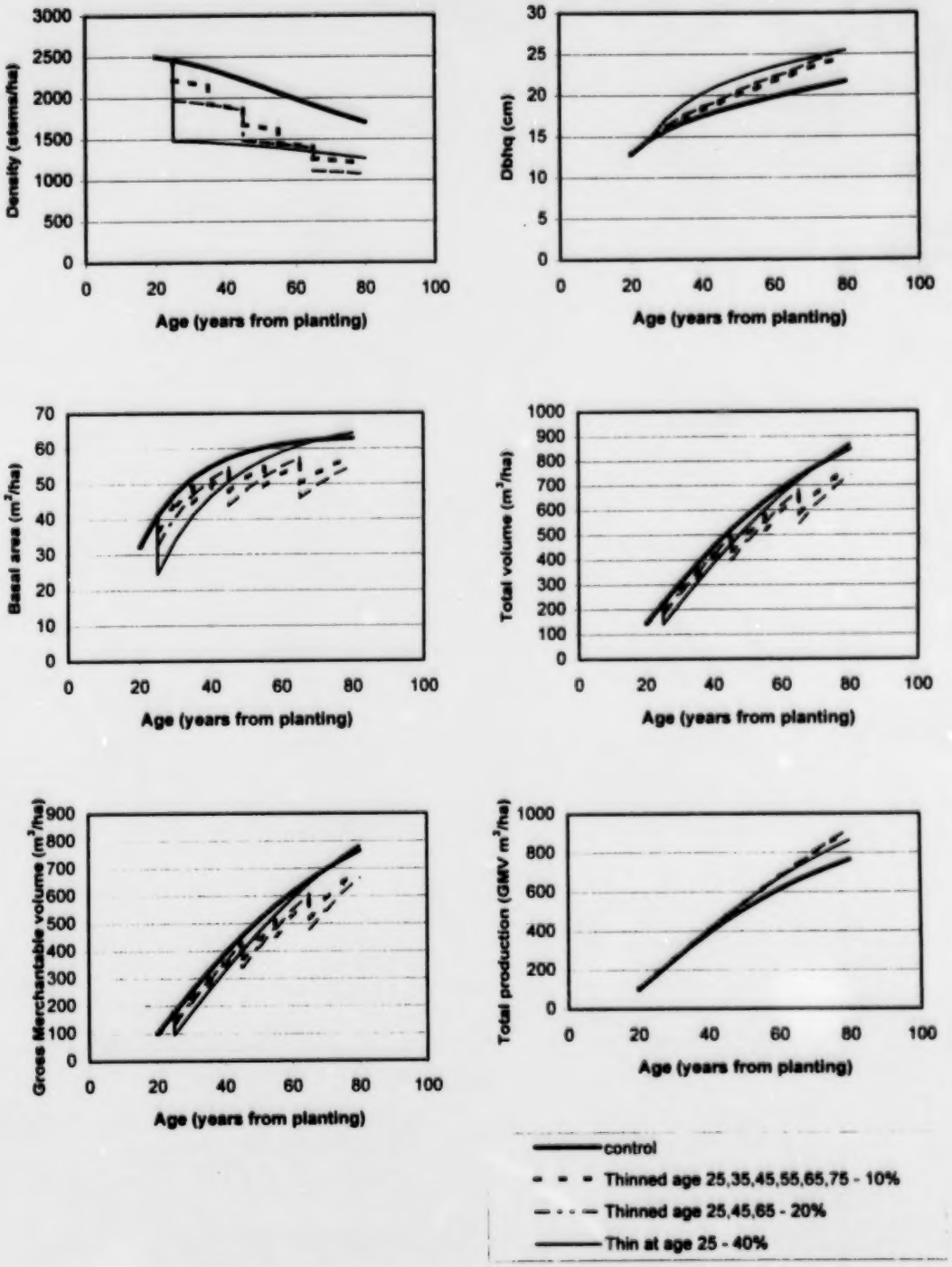

Figure 15. Models predicted response to various thinnings at different levels of intensity and timing. Site index (m @ bh age 50) is 24 and initial density is 2500 stems/ha.

Table 7. Predicted response to various thinnings at different levels of intensity and thinning.

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	145.8	99	99	
25	12.0	2467	14.6	41.0	225.8	175	175	15.1
30	14.3	2419	15.8	47.3	305.5	250	250	15.1
35	16.5	2361	16.7	51.8	382.1	323	323	14.5
40	18.6	2293	17.5	55.0	454.0	391	391	13.6
45	20.5	2220	18.1	57.4	520.6	454	454	12.6
50	22.3	2143	18.7	59.2	581.7	512	512	11.6
55	24.0	2065	19.3	60.4	637.4	564	564	10.5
60	25.6	1988	19.8	61.3	688.1	612	612	9.6
65	27.0	1912	20.3	62.0	734.2	656	656	8.7
70	28.4	1839	20.8	62.4	776.1	696	696	7.9
75	29.7	1769	21.3	62.8	814.4	732	732	7.2
80	30.9	1703	21.7	63.0	849.4	765	765	6.6

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 24m @ 50 years breast-height age
Density: **2500** stems/ha

= indicates age of thinning

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	145.8	99	99	
25	12.0	2467	14.6	41.0	225.8	175	175	15.1
30	14.3	2188	16.0	44.1	298.1	232	252	15.4
35	16.5	2147	17.1	49.4	364.9	307	327	14.9
40	18.6	1899	18.2	49.3	408.6	348	401	14.9
45	20.5	1861	19.1	53.1	482.5	418	471	14.0
50	22.3	1646	20.0	51.7	510.2	444	541	14.1
55	24.0	1614	20.8	54.7	579.0	509	606	13.0
60	25.6	1429	21.7	52.7	593.0	522	673	13.3
65	27.0	1404	22.4	55.4	657.4	583	734	12.2
70	28.4	1246	23.0	52.9	660.0	586	797	12.6
75	29.7	1226	24.0	55.4	720.9	643	858	11.5
80	30.9	1206	24.6	57.5	776.5	696	907	10.5

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	145.8	99	99	
25	12.0	2467	14.6	41.0	225.8	175	175	15.1
30	14.3	1714	16.7	37.5	245.7	194	254	15.7
35	16.5	1697	18.2	44.1	327.4	271	331	15.5
40	18.6	1675	19.3	49.0	405.9	345	405	30.3
45	20.5	1648	20.2	52.8	480.4	416	476	14.1
50	22.3	1618	21.0	55.9	550.1	482	542	13.2
55	24.0	1586	21.6	58.2	614.8	543	603	12.3
60	25.6	1101	22.9	45.5	514.5	448	678	15.0
65	27.0	1091	24.0	49.3	587.6	517	747	13.6
70	28.4	1079	24.9	52.5	655.0	581	811	12.8
75	29.7	1067	25.7	55.1	717.1	640	870	11.7
80	30.9	1053	26.3	57.3	774.2	694	924	10.8

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	1473	17.2	34.0	224	174	253	15.6
35	16.5	1463	18.9	41.1	307	251	331	15.6
40	18.6	1449	20.2	48.5	386	327	406	15.1
45	20.5	1433	21.2	50.8	462	399	478	14.4
50	22.3	1414	22.1	54.2	534	467	548	13.6
55	24.0	1393	22.8	56.9	601	530	610	12.7
60	25.6	1369	23.4	59.1	664	590	669	11.8
65	27.0	1345	24.0	60.9	722	644	724	11.0
70	28.4	1319	24.5	62.4	775	695	775	10.1
75	29.7	1293	25.0	63.5	824	741	821	9.3
80	30.9	1266	25.5	64.5	869	784	863	8.5

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	145.8	99	99	
25	12.0	2467	14.6	41.0	225.8	175	175	15.1
30	14.3	1230	17.7	30.4	201.6	152	252	15.3
35	16.5	1224	19.8	37.9	283.7	230	329	15.5
40	18.6	1217	21.4	43.7	363.9	306	405	15.2
45	20.5	1208	22.6	48.4	440.9	379	478	14.6
50	22.3	1197	23.5	52.1	514.3	448	547	13.9
55	24.0	1184	24.4	55.2	583.6	513	613	13.1
60	25.6	1170	25.1	57.7	648.6	575	675	12.3
65	27.0	1155	25.7	59.8	709.3	632	732	11.5
70	28.4	1139	26.2	61.6	765.7	686	785	10.7
75	29.7	1122	26.7	63.0	817.9	735	835	9.9
80	30.9	1104	27.2	64.3	866.1	781	880	9.1

Age	Topht (m)	Density (stems/ha)	Dbhq (cm)	BA (m^2/ha)	GTV (m^3/ha)	GMV (m^3/ha)	GMV Total Prod (m^3/ha)	PAI GMV (m^3/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	985	18.5	26.4	177	129	248	14.7
35	16.5	983	21.1	34.2	258	205	325	15.3
40	18.6	979	22.9	40.4	338	281	400	15.1
45	20.5	975	24.4	45.4	415	354	473	14.8
50	22.3	969	25.5	49.5	489	424	543	14.0
55	24.0	963	26.4	52.9	560	491	610	13.3
60	25.6	956	27.2	55.7	626	554	673	12.6
65	27.0	948	27.9	58.1	689	613	733	11.9
70	28.4	939	28.6	60.2	748	669	789	11.2
75	29.7	929	29.1	61.9	803	721	841	10.4
80	30.9	919	29.6	63.4	855	770	890	9.7

Top Height = average height of the 100 largest diameter trees per hectare (m).
Density = stems per hectare.
Dbhq = stand quadratic mean diameter (cm).
BA = stand basal area (m^2) per hectare
GTV = gross total volume (m^3/ha).
GMV = gross merchantable volume (m^3/ha) (30 cm stump height - 10 cm upper diameter).
Total Prod = accumulated GMV volume (includes thinning volume) No mortality volume included.
PAI = periodic annual increment.

Table 7. Predicted response to various thinnings at different levels of intensity and thinning.

Unmanaged and Managed Yield Tables and Charts for Red Pine (*Pinus resinosa* Ait.)

Site Index: 24m @ 50 years breast-height age
Density: 2500 stems/ha

= indicates age of thinning

Age	Top Ht (m)	Density (stems/ha)	Dbhq (cm)	BA (m²/ha)	GTV (m³/ha)	GMV (m³/ha)	GMV Total Prod (m³/ha)	PAI GMV (m³/ha/yr)
20	9.5	2500	12.8	32.2	145.8	99	99	
25	12.0	2467	14.6	41.0	225.8	175	175	15.1
30	14.3	2419	15.8	47.3	305.5	250	250	15.1
35	16.5	2361	16.7	51.8	382.1	323	323	14.5
40	18.6	2293	17.5	55.0	454.0	391	391	13.6
45	20.5	2220	18.1	57.4	520.8	454	454	12.6
50	22.3	2143	18.7	59.2	581.7	512	512	11.6
55	24.0	2065	19.3	60.4	637.4	564	564	10.5
60	25.6	1988	19.8	61.3	688.1	612	612	9.6
65	27.0	1912	20.3	62.0	734.2	656	656	8.7
70	28.4	1839	20.8	62.4	776.1	696	696	7.9
75	29.7	1769	21.3	62.8	814.4	732	732	7.2
80	30.9	1703	21.7	63.0	849.4	765	765	6.6

Age	Top Ht (m)	Density (stems/ha)	Dbhq (cm)	BA (m²/ha)	GTV (m³/ha)	GMV (m³/ha)	GMV Total Prod (m³/ha)	PAI GMV (m³/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	1953	16.3	40.9	266	213	253	15.6
35	16.5	1925	17.6	46.8	347	289	329	15.2
40	18.6	1891	18.6	51.2	424	362	402	14.5
45	20.5	1852	19.4	54.6	496	430	470	13.7
50	22.3	1483	20.5	48.3	478	414	544	14.8
55	24.0	1442	21.4	52.0	551	483	613	13.8
60	25.6	1418	22.2	54.9	618	548	677	12.7
65	27.0	1392	22.9	57.3	680	605	735	24.4
70	28.4	1102	23.9	49.5	619	547	803	13.6
75	29.7	1090	24.8	52.8	685	609	868	12.4
80	30.9	1076	25.5	55.1	745	666	922	11.4

Age	Top Ht (m)	Density (stems/ha)	Dbhq (cm)	BA (m²/ha)	GTV (m³/ha)	GMV (m³/ha)	GMV Total Prod (m³/ha)	PAI GMV (m³/ha/yr)
20	9.5	2500	12.8	32.2	145.8	99	99	
25	12.0	2467	14.6	41.0	225.8	175	175	15.1
30	14.3	1714	16.7	37.5	245.7	184	254	15.7
35	16.5	1697	18.2	44.1	327.4	271	331	15.5
40	18.6	1675	19.3	49.0	405.9	345	405	30.3
45	20.5	1648	20.2	52.8	480.4	418	478	14.1
50	22.3	1618	21.0	55.9	550.1	482	542	13.2
55	24.0	1586	21.6	58.2	614.8	543	603	12.3
60	25.6	1101	22.9	45.5	514.5	448	678	15.0
65	27.0	1081	24.0	49.3	587.8	517	747	13.8
70	28.4	1079	24.9	52.5	655.0	581	811	12.8
75	29.7	1067	25.7	55.1	717.1	640	870	11.7
80	30.9	1053	26.3	57.3	774.2	694	924	10.6

Age	Top Ht (m)	Density (stems/ha)	Dbhq (cm)	BA (m²/ha)	GTV (m³/ha)	GMV (m³/ha)	GMV Total Prod (m³/ha)	PAI GMV (m³/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	226	175	175	15.1
30	14.3	1473	17.2	34.0	224	174	253	15.6
35	16.5	1463	18.9	41.1	307	251	331	15.6
40	18.6	1448	20.2	46.5	386	327	406	15.1
45	20.5	1433	21.2	50.8	462	399	479	14.4
50	22.3	1414	22.1	54.2	534	467	546	13.6
55	24.0	1393	22.8	56.9	601	530	610	12.7
60	25.6	1369	23.4	58.1	664	590	669	11.8
65	27.0	1345	24.0	60.9	722	644	724	11.0
70	28.4	1319	24.5	62.4	775	695	775	10.1
75	29.7	1293	25.0	63.5	824	741	821	9.3
80	30.9	1266	25.5	64.5	869	784	865	8.5

Age	Top Ht (m)	Density (stems/ha)	Dbhq (cm)	BA (m²/ha)	GTV (m³/ha)	GMV (m³/ha)	GMV Total Prod (m³/ha)	PAI GMV (m³/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	225	175	175	15.1
30	14.3	995	16.5	26.4	177	129	248	14.7
35	16.5	983	21.1	34.2	258	205	325	15.3
40	18.6	970	22.9	40.4	336	281	400	15.1
45	20.5	975	24.4	45.4	415	354	473	14.8
50	22.3	969	25.5	49.5	490	424	543	14.0
55	24.0	953	26.4	52.9	560	491	610	13.3
60	25.6	936	27.2	55.7	626	554	673	12.6
65	27.0	940	27.9	58.1	689	613	733	11.9
70	28.4	939	28.6	60.2	748	669	789	11.2
75	29.7	929	29.1	61.9	803	721	841	10.4
80	30.9	919	29.6	63.4	856	770	889	9.7

Age	Top Ht (m)	Density (stems/ha)	Dbhq (cm)	BA (m²/ha)	GTV (m³/ha)	GMV (m³/ha)	GMV Total Prod (m³/ha)	PAI GMV (m³/ha/yr)
20	9.5	2500	12.8	32.2	146	99	99	
25	12.0	2467	14.6	41.0	225	175	175	15.1
30	14.3	1230	17.7	30.4	201.8	152	252	15.3
35	16.5	1224	19.8	37.9	283.7	230	329	15.5
40	18.6	1217	21.4	43.7	363.9	309	405	15.2
45	20.5	1208	22.6	48.4	440.9	379	478	14.8
50	22.3	1197	23.5	52.1	514.3	448	547	13.9
55	24.0	1184	24.4	55.2	583.6	513	613	13.1
60	25.6	1170	25.1	57.7	648.6	575	675	12.3
65	27.0	1155	25.7	59.8	709.3	632	732	11.5
70	28.4	1139	26.2	61.6	765.7	686	785	10.7
75	29.7	1122	26.7	63.0	817.9	735	835	9.9
80	30.9	1104	27.2	64.3	866.1	781	880	9.1

Top Height = average height of the 100 largest diameter trees per hectare (m).
Density = stems per hectare.
Dbhq = stand quadratic mean diameter (cm).
BA = stand basal area (m^2) per hectare
GTV = gross total volume (m^3/ha).
GMV= gross merchantable volume (m^3/ha) (30 cm stump height - 10 cm upper diameter).
Total Prod = accumulated GMV volume (includes thinning volume) No mortality volume included.
PAI = periodic annual increment.

short term wood supply shortages and satisfy adjacency constraints. Loftus (1997) found no increase in yield with thinning (from PSPs primarily in coastal Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] and western hemlock) (*Tsuga heterophylla* (Raf.) Sarg.) Smithers (1954) recommended light (retaining >70% basal area), frequent (from 5 years at the first half of the rotation to 15 years in the second half) thinnings in order to increase yields from red pine. At Rockland, 72 years after planting, the total production of the unthinned stand (including mortality) exceeded that of the thinned stand (von Althen and Stiell 1990). However, the standing volume of the unthinned stand was less than the standing volume plus thinning removals of the thinned stand.

Cochran and Dahms (1998) and Cochran and Barret (1998), with lodgepole (*Pinus contorta* Dougl.) and ponderosa pine (*Pinus ponderosa* Laws.) respectively, found the highest merchantable volumes (to a 7.6cm top) were achieved at a 1.8m spacing while the highest board foot volumes (12.7cm top) were achieved at wider spacings or heavier thinnings (approximately 3.5–5.5m spacing).

Some authors contend that thinning should increase the total volume yield. Pienaar (1979) developed a model for basal area growth based on the expectation that a thinned plantation with the same age and stem density as an unthinned plantation will approach and eventually equal the unthinned plantation in terms of total and average basal area. REDPTHIN (Rose and Chen 1995) predicts that thinning will produce more total volume than not thinning.

From the plantations examined here, thinning does not increase yields appreciably unless there is fairly significant mortality (as in the cases of stands impacted by pathogens—Hendm15, Neorr6, Vivian15). Unthinned stands with high basal areas may undergo significant mortality and loss of volume. Thinning does reduce the rate of mortality, particularly catastrophic mortality. However, the risk of windthrow increases immediately after commercial thinning (Navratil 1997).

Gains from thinning in terms of diameter increment and future higher-valued products are considerable. Figure 16 illustrates the earlier development of higher-value product (in this case utility pole and sawlog) volume following a total of four thinning interventions. Earlier production of poles and or sawlog volume is generally achieved through heavier thinning regimes. This is not surprising, since increased d_g growth is related to residual growing space. Resource managers will have to determine an acceptable balance between maximizing individual tree growth (for desired products) and maintaining adequate stocking levels to obtain desired tree quality standards. In addition, economics, wildlife habitat and aesthetic values need to be considered when making management decisions.

Conclusions

Red pine plantation development can be predicted using a stem change and d_g change model. Thinning significantly increases d_g growth and decreases mortality. Total production of a thinned plantation is higher than that on a comparable unthinned plantation. In the dataset, total production, combined with the volume lost to mortality, was higher in the control plots than the thinned plots. Volume gains from thinning are due to the reduction of density-related mortality. The gains in total volume production as a result of thinning need to be weighed against the additional cost associated with intermediate thinnings.

Total production is relatively similar for a broad range of thinning prescriptions. For example, thinning 10% every 10 years, 20% every 20 years or 30% every 30 years (Table 7) results in a difference of 30m³/ha GMV (3%) at 80 years from planting. Similarly, removing 25%, 33%, or 40% at ages 25 and 40 results in a difference of 39m³/ha GMV (4%) at 80 years.

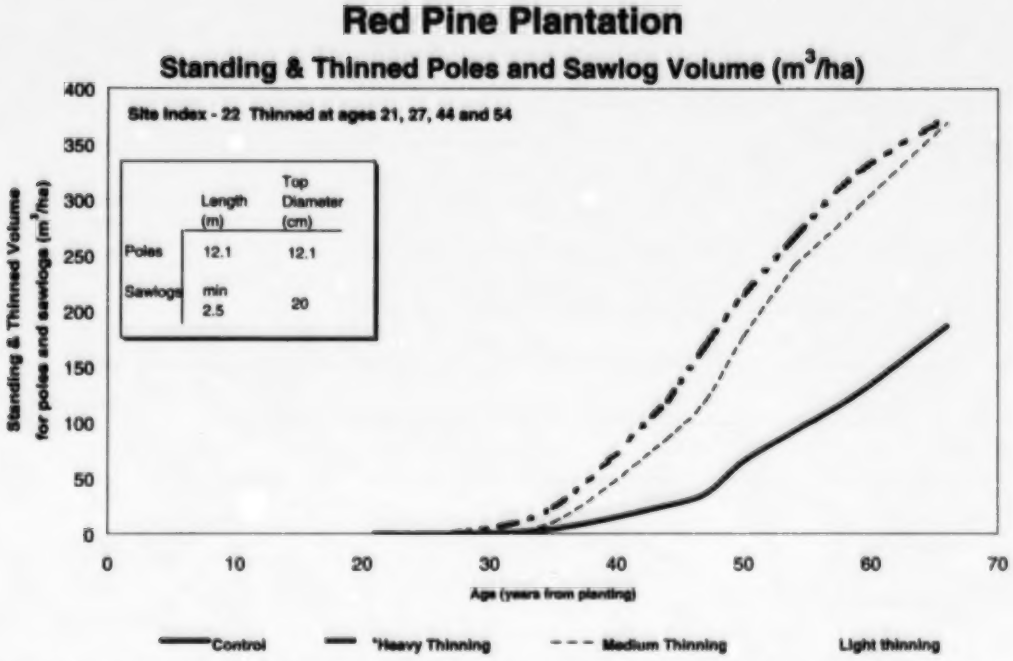

Figure 16. Example of earlier product volume development following four thinning intensities in a red pine plantation.

Thinning results in larger, higher-valued products sooner. As well, thinning may be beneficial to the overall health of the stand by maintaining tree vigour and decreasing susceptibility to forest pests provided that thinning operations do not harm the residual stand.

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Appendix A

The diameter growth and density change models were calibrated on the control plots. The models were subsequently evaluated on the thinned plots using the following algorithm. The algorithm was also used to produce figures 4-8.

1. Initialize the d_g, density, basal area, and age using the data from the first measurement of the plot.
2. Project the d_g and density to the next remeasurement in annual steps, updating the basal area after each year's projection.
3. Compare the projections to the actual remeasurement (pre-thinning values).
4. If the plot was thinned at the remeasurement reset the predicted density to the post-thinning density prior to any further projections. Note that d_g was not reset to the post-thinning d_g. In effect, this assumes trees are randomly selected for thinning.

The results of using the model to project the thinned plots are given in the Table A1 and Figure A1. Both absolute and relative errors are presented in Table A1. Relative errors are plotted on Figure A1.

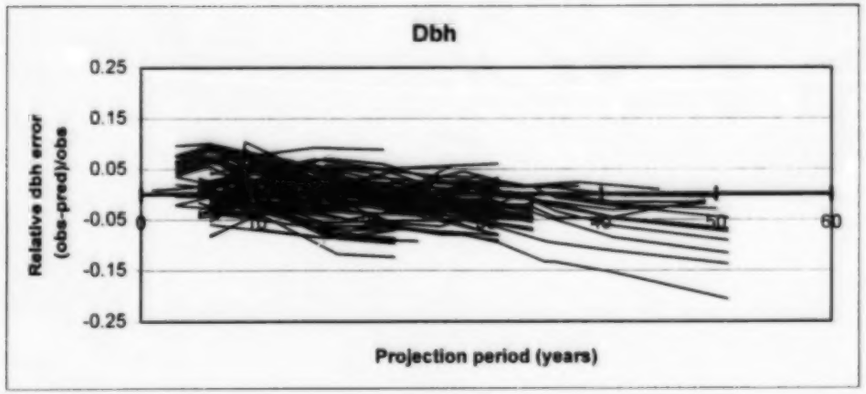
It should be noted that stands exhibiting the largest errors are stands that are either being initialized at older ages (50+ years from planting) or stands that are suffering basal area decline. For the latter, it is hypothesized that these stands are affected by some extreme environmental stress (e.g., disease, windthrow, etc.) not recorded in the stand records, and are not truly representative of normal rates of healthy red pine stand development.

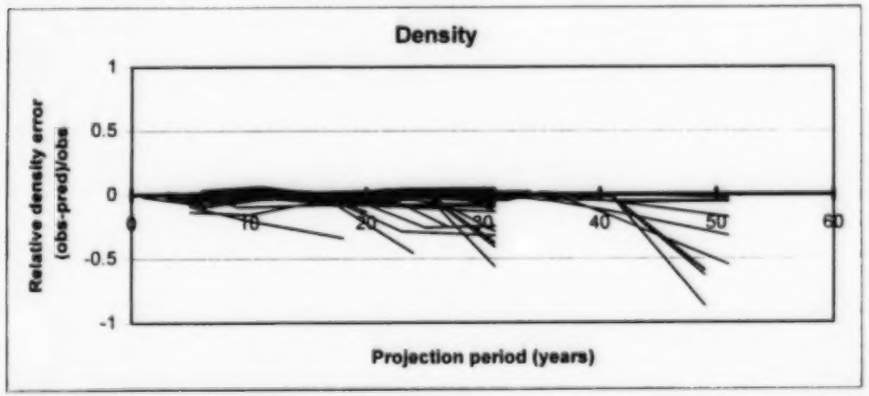
Tabe A1. Absolute and relative errors of the model for a range of projection periods.

		Absolute Error Estimates*			Relative Error Estimates**		
Projection period (years)	Number of observations	Dbh (cm)	Density (stems/ha)	Basal area (m^2/ha)	Dbh (cm)	Density (stems/ha)	Basal area (m^2/ha)
1-5	50	0.24	-11.08	0.37	0.02	-0.01	0.04
6-10	129	0.30	-11.97	0.62	0.02	-0.01	0.03
11-15	86	0.27	-0.33	0.81	0.01	0.00	0.03
16-20	79	-0.17	-20.13	-1.32	-0.01	-0.01	-0.03
21-25	85	-0.27	-31.33	-2.26	-0.01	-0.02	-0.05
26-30	36	0.01	-10.85	-0.59	0.00	-0.02	-0.02
31-35	67	-0.64	-28.78	-3.95	-0.03	-0.04	-0.10
36-40	11	-0.77	-5.59	-2.40	-0.03	-0.01	-0.07
41-45	14	-1.27	-24.51	-4.73	-0.05	-0.03	-0.14
46-50	5	-0.50	-144.64	-12.10	-0.02	-0.42	-0.46
51-55	7	-2.95	-95.96	-13.73	-0.11	-0.17	-0.45
Average	569	-0.10	-18.45	-1.17	0.00	-0.02	-0.03

* Error calculated as (observed value - predicted value)

** Relative error calculated as (observed - predicted)/observed





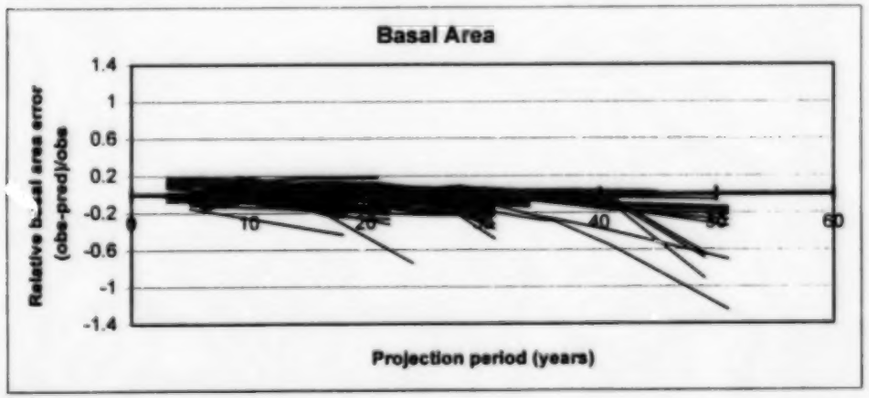


Figure A1. Relative error projections of Dbh, density, and basal area for a range of projection periods.

Appendix B

Suggested model form for stands exhibiting or susceptible to *Armillaria* root disease.

The model below was fit to the same data set as presented in the body of this report with the addition of three other control plots that showed significant mortality, Hendm15, Neorr6 and Vivian 13 (see Figure B1). Site visits to these plots indicated considerable *Armillaria* infection. Inclusion of these three plots affected mainly the stem change model, increasing the rate of mortality. The model form presented in the body of this report was used. The parameter estimates are given below.

$$\Delta d_q = \alpha \cdot d_q^{\beta} \cdot e^{\gamma+\delta \cdot G+\varphi \cdot age}$$

where

$\alpha = 3.000$
$\beta = 0.31148936$
$\gamma = -1.157613583$
$\delta = -0.047848008$
$\varphi = -0.002928629$
$MSE = 0.00763, df = 165$

$$\Delta N = -\gamma \cdot N^3 \cdot (1 - e^{(\alpha+\beta G)age})$$

where

$\alpha = 0.000058526$
$\beta = -0.000021744$
$\gamma = 0.0000000320$
$MSE = 410, df = 172$

These parameter estimates should be used if a red pine plantation is exhibiting excessive mortality. Note that this "crashing" was only observed in unthinned (control) plots with 1.7m to 2.0m spacing. Adjacent thinned plots did not show unusually high rates of mortality. Figure B1 presents the model fit to the three infected plots.

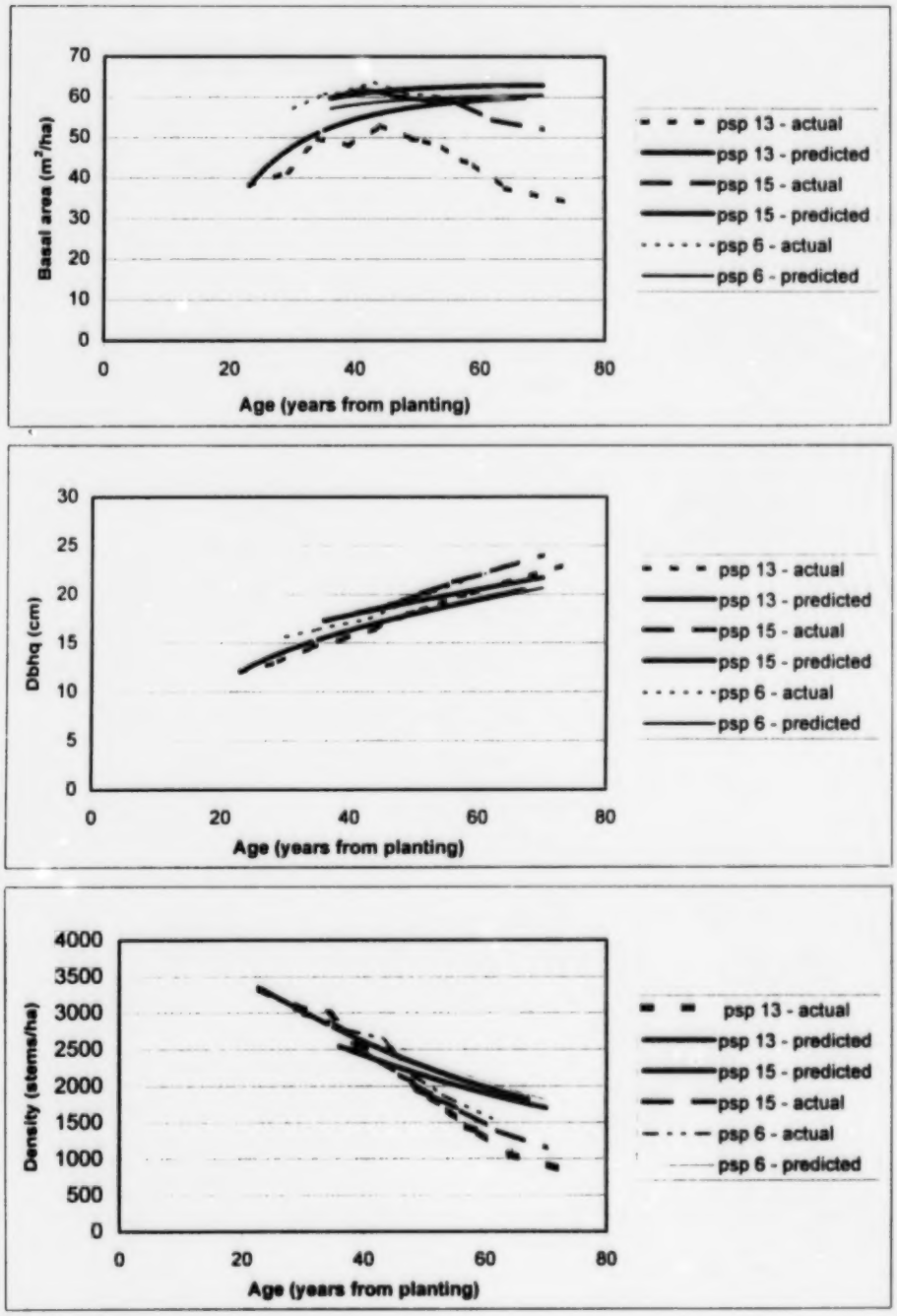


Figure 17. Predictions for *Armillaria* impacted Vivian, Hendrie and Norrock plots compared to actual plot data.